VOLUME 83 NO. HW4
SEPTEMBER 1957

JOURNAL of the

Highway Division

PROCEEDINGS OF THE

AMERICAN SOCIETY

OF CIVIL ENGINEERS

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This Journal is published by the American Society of Civil Engineers. Publication office is at 2500 South State Street, Ann Arbor, Michigan. Editorial and General Offices are at 33 West 39 Street, New York 18, New York. $4.00 of a member's dues are applied as a subscription to this Journal.

AT,BD,CP,CO,HW,IR,SU,WW,PL

Journal of the
HIGHWAY DIVISION
Proceedings of the American Society of Civil Engineers

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Paper 1371 September, 1957 HW 4

Journal of the
HIGHWAY DIVISION
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THE CITY'S PLACE IN THE EXPANDED HIGHWAY PROGRAM[a]

Alfred Berarducci[1] and Glen C. Richards
(Proc. Paper 1371)

With the enactment of the 1956 Federal Highway Law, a tremendous impact will be brought to bear upon the entire highway building industry. This Law, in addition to extending the provisions of the existing Federal Aid Laws (the customary 50-50 matching contributions), increased the Interstate system funds to substantial proportions. What will be the position of the cities and the metropolitan areas in this expanded highway program? For a few cities, it will be an accelerated continuation of programs initiated immediately after World War II, but for the majority of cities, it will be a new experience—an experience which includes problems and difficulties never before encountered in providing a public improvement.

Those cities which have been engaged in the problem of providing modern-day highway facilities for their communities will draw upon their recently accumulated experiences to meet the new responsibilities. These cities will have been initiated into the complexities of dealing with the multitude of details involved in starting from scratch and pursuing the matter through to completion. For the others, it will be a challenge—but certainly a worthwhile challenge when the final benefits are considered.

Since more than half of the Federal funds are earmarked for urban areas, what can the cities do to obtain their proper share of these most urgently needed funds? It appears that two very important steps must be taken by most cities, and the cities themselves must take the initiative in this matter.

I. The cities must develop, at the earliest opportunity, a realistic and practical appraisal of their street and highway needs.

II. Agreements must be reached with their State Highway Department to finance and construct the needed facilities in an orderly fashion based on priorities developed from factual traffic information.

Note: Discussion open until February 1, 1958. Paper 1371 is part of the copyrighted Journal of the Highway Division of the American Society of Civil Engineers, Vol. 83, No. HW 4, September, 1957.

a. Presented at a meeting by the ASCE at Jackson, Miss., February 13-22, 1957.

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Developing Traffic Needs

How do we approach the problem of preparing and developing a traffic needs program and the estimated cost of such a program? Unfortunately, this is the stage at which most cities are delinquent. Since the Federal Highway Program is based on the traffic needs of the Nation, it is axiomatic that the cities must furnish, at the earliest opportunity, their traffic needs program. In view of the long-range Federal program, it will now be possible for cities and metropolitan areas to plan their major traffic system and requirements on a long-range basis, rather than on a piece-meal, year-to-year basis. Since long-range planning will include exploration of the entire future redevelopment of a city, it is appropriate to discuss the city's master plan and its purpose. A traffic needs study must be made in conjunction with the master plan of the city. The load to be carried will be determined from traffic studies which must be coordinated with the entire master plan.

The master plan for a city should be an all-inclusive, comprehensive long-range plan for the future development or redevelopment of a city. In many cases, cities will come to realize that the time has come to abandon or scrap what has become obsolete and to rebuild anew. It will be found that a city loses taxes and revenues from old, obsolete installations. Certainly it will cost money to redevelop and rebuild, but in the long run that cost will be returned manyfold.

The master plan then, is intended to be a general overall scheme designed to modernize the city over the years ahead by establishing a pattern and a program to guide its normal growth or regrowth. It is not a single plan, but a series of coordinated plans which aim to encourage the best possible use of all the land within a city's present boundaries, and to establish the general location of all contemplated public improvements. It should be obvious that no one single major improvement should be installed without considering its effect on the entire city development. In our city, the master plan deals with the following elements: Land-use and Zoning; Redevelopment and Rebuilding of Declining Areas; Schools and Education; Community Service Facilities; Traffic and Thoroughfares; Recreation; A Civic and Cultural Center; and Development of Waterfront Areas. Essentially, the master plan should represent the present-day conception of the city of the future and should be prepared with full knowledge that many of its details will necessarily be changed as developments occur which cannot be foreseen at this time.

Since the master plan includes all of the physical elements that form the community, it necessarily involves most of the operating departments of a city. In most cases, the operating departments themselves are charged with responsibility for the long-range development of its particular facility. It is recognized, however, that the individual features of a city cannot be adequately planned alone, but most be planned in proper relationship to all the others. It is not reasonable to have one group of men plan the street and highway system of a city, another the parks system, another the area to be set aside for industries, business, and homes, and still another the sewerage and water supply system. Such procedures might be dangerous, unless arrangements are made for these men to work closely together following a general plan agreed upon, so that each may know what the other is doing. For this reason, the preparation of a master plan is generally a function of a city planning commission, or its equivalent. The planning commission staff

should be a professional group experienced in this type of work or should have access to considerable professional advice. In many cases, they will work under the direction of non-professional, civic-minded persons and groups. The plan itself, however, should be prepared by a planning group with the cooperation and active assistance of all operating departments in a community.

The master plan should attempt to set objectives for a period of 25 to 30 years ahead. Its provisions fall into two groups: (1) Those which affect private building activities, and (2) Those which involve public improvements or require public funds. The first group will come about largely through the regulations of Land-use as established by a Zoning ordinance. The second group of master plan provisions will depend for their realization upon the rate at which public funds can be made available. The adoption of the master plan should mark the end of the period in which homes, business and commerce, and industries should have to compete with each other for space in the city to the detriment of each.

The Land-Use Plan

The foundation and the principal tool of the master plan is the Land-Use Plan. The regulation and the operation of land-use is handled by a zoning ordinance. Zoning is the process of dividing the city into districts or zones for the purpose of regulating the use of land and buildings, the height, area, and bulk of buildings, and the density of population. The regulations in similar districts must be identical, but the regulations in unlike districts may be different. The adoption of a zoning ordinance for a city is not a simple matter. Many obstacles and objections will have to be overcome, usually from special interest pressure groups. In our own city, a zoning ordinance was not adopted until 1940, after numerous attempts in the previous years had failed.

The Land-Use Plan will show areas suitable for residential, industrial, commercial, recreational, and public uses, in addition to the routes of principal traffic thoroughfares. It may well be that over a period of time all the single parts or buildings of a city will become obsolete and will have to be replaced. These replacements are gradual and may take place without changing the basic framework of the street system. The possibilities for change might be limited by the existing pattern of interdependent thoroughfares, industries, railroads, and utilities. On the other hand, there is no valid reason why the existing street pattern of any city could not be changed in some respects. This might be the time for new thinking along these lines with respect to a more efficient layout of a city's street system. With the acceptance of modern type highways as a basic requirement for moving traffic in highly congested areas, the time has come to include high capacity thoroughfares, such as freeways or expressways, in a city's street pattern. In general, it may be desirable and also more economical to locate these high type facilities on new alignment. Using the master plan as a basis, these modern type trafficways may act as boundaries enclosing residential areas and separating them from one another. With certain adjustments of these boundaries, it may be possible to define natural communities within the larger community. These natural communities can be developed into reasonably self-contained sub-cities; the living areas, industries, shopping centers, major highways and public facilities can be so rearranged as to

bring about a city community life consistant with modern-day living, although it is admitted that some disturbances will be caused by this rearrangement. The natural communities, in turn, can be further sub-divided into neighborhood units whose boundaries again are determined by physical features of lesser influence.

A word of caution is in order! It is realized that the perfect plan can finally be prepared if time is of no consequence. However, practical matters must be taken into consideration and decisions must be reached, otherwise there is no end to city planning and a final needs study will never be completed. Talking must end at some point, plans must be completed, and construction must start, because the thousands of motor vehicles who want to use our streets and highways cannot drive on plans and blueprints, and they cannot drive over delicately-made scale-models. A common understanding must be reached by the ivory tower thinkers, and those who are concerned with practical matters and the problem of eventually completing a useable facility.

The Trafficways Plan

The Trafficways Plan will be one element of the master plan. In order to develop an acceptable trafficways plan, the combined and joint efforts of various technical groups will be required. This will include city planners, traffic engineers, street and highway engineers, construction engineers, maintenance engineers, and the engineers of the adjoining communities, counties, and the State Highway Department. Its realization will, of course, be governed by the availability of funds and the desires of the people. But whether the system is built in a short time or over a period of years, the plan will give the city a guide to govern street and highway construction in the years ahead. From this plan, realistic cost estimates can be prepared, which, in effect, will result in the needs of the community.

Inevitably, technical groups will discover that a basic conflict exists between city planning requirements and the requirements for moving traffic, persons, and goods. These basic conflicts must be brought together and adjusted to the other features of desirable, future community life. The plans of adjoining communities must be taken into account, and in a sense the entire area requirements must be considered. This part of the master plan should not attempt to fix the precise location or design of any of the features with which it deals. It should show, however, what facilities are required, where they should be located, and how they should fit into the general scheme of future development. The precise details will be left to those agencies that will prepare the construction plans and will be responsible for executing the work. Finally developed, the trafficways plan should be a plan for location and improvement of arterial highways and thoroughfares which will permit a free flow of urban traffic within and through the city. The intention should be to interconnect the principal commercial and industrial concentrations with the residential neighborhoods and communities of the metropolitan area.

Expressways or freeways will be the highest type of facility incorporated in the plan, and generally will be superimposed upon the present street system, with modifications in that system as required to fit the freeway plan. These highways are especially designed to carry an uninterrupted flow of through traffic. They are distinguished by the following features of design:

(1) Access is limited to a few selected points of entrance and exit (2) Continuous physical separations of opposing streams of traffic, and (3) Separation of grades at all intersections. With an accepted Land-Use Plan, it will be possible to locate these traffic arteries with full knowledge of whether they will be passing through industrial or residential areas, and with some indication of the probable intensity of that development. They will be located where they can be of maximum usefulness as trafficways, and incidentally benefit, rather than blight, the property adjacent to them. While freeways are designed primarily as high speed routes to interconnect the communities of the metropolitan area, they have the incidental feature of being wide, landscaped strips. Fully recognized, this feature will be an asset to the sections through which they pass. Routing of expressways or freeways at the boundaries of communities, or between residential and industrial areas, has frequently served the purpose of providing useful separations or buffers. At the same time, routing of expressways through residential communities, in such a way that schools, shopping centers, or public facilities would be cut off from their service areas, must be avoided whenever possible. It has generally been desirable to locate routes in such a manner as to avoid the creation of isolated or remnant areas that would be difficult to service or be inadequate in size for proper use or development.

If planning is done along those lines, and in conjunction with the entire master plan, these modern facilities should give impetus to the rebuilding of a city, break the metropolitan area traffic bottle-neck, provide for slum clearances, halt urban decay, and assure the future economic growth of a city.

The technique of evaluating the Trafficways Plan and of arriving at the estimated needs costs has been well established. Competent engineers, both public and privately employed, are well versed in this matter. In Michigan, as well as in many other States, the Automotive Safety Foundation has conducted state-wide needs studies which included the individual requirements of all the cities, in addition to the needs of the State and the Counties.

Another method of preparing the needs and requirements of individual cities has been developed by the National Committee on Urban Transportation. The work of the National Committee on Urban Transportation can well be utilized by all cities, regardless of size, in their attack on this subject. This National Committee is a group of semi-public agencies interested and organized for the express purpose of aiding cities in determining their particular transportation problem and for arriving at a solution.

The methods and procedures developed by the National Committee are specifically designed to show local governments how to carry out comprehensive fact-gathering programs on a uniform basis and in an economical manner by the use of available staff personnel. From the municipal point of view, it is a step by step guide which the municipal official can follow in evaluating existing facilities and future needs. It is recognized that the facts will not, in themselves, produce results, but with these facts, officials at all levels of government and the public can be informed as to existing and future needs with greater accuracy. The availability of adequate factual information will make it possible for cities to demonstrate and justify their transportation needs on a uniform basis. Data uniformly assembled and maintained will permit closer integration of state, metropolitan area and local planning. Utilizing these uniform methods and standards, cities can make direct comparison of the facts developed and experiences gained. It will be an efficient

means for collecting useful data on a national scale.

It was determined by the National Committee that the preparation of a Manual of economic methods and procedures, which could be used by cities and local governments to undertake data-collecting programs on a uniform continuing basis, would best meet their objectives. The Manual was prepared by nine sub-committees and the work was divided into logical study areas.

The Manual contains chapters on: Administration, Laws and Ordinances, Financial Records and Reports, Travel Desires, Measurement of Existing Street Services, Inventory of Existing Street Facilities, Measurement of Existing Transit Service, Recommended Standards for Street Services and Facilities, and Recommended Standards, Warrants, and Objectives for Transit Facilities and Service.

The section on Travel Desires contains short methods and techniques for making and using modified Origin and Destination traffic studies. This study is the foundation upon which future needs can be estimated and by which existing facilities can be modernized to the most efficient level of service that can be anticipated at a given time. The chapter on Existing Street Services describes economical techniques for determining the level of services provided by the existing street system in terms of capacity, speed, safety, convenience, and terminal facilities. It recommends use of the sample technique for measuring traffic volume trends. This method, when combined with an inventory of parking facilities, travel speed studies, cordon counts, and other information, will form a complete picture of traffic trends and demands as they develop. The Inventory of Existing Street Facilities will provide a city with complete information on the extent and physical condition of its street system, the pavement and right-of-way widths, type, age and condition of pavement, traffic signs and signals, parking regulations, street lighting, and a great deal of additional information. An inventory of this type is indispensable in planning improvements on the existing street system and the development of adequate maintenance programs.

By the use of guides and standards in another section, a community can evaluate the service provided by the existing streets, highways and terminal facilities. It provides criteria for classifying an urban street system by function and standards for geometric and functional designs. In a similar manner, another chapter provides a yard stick by which transit management and public officials can measure the facts and information pertaining to those facilities. Each of the nine chapters of the Manual is complete in itself, and if desired, a community can utilize one or several at a given time, depending upon which particular part of the program is given first priority. The greatest value, however, can only be derived through the use of the entire Manual.

Improving the movement of people and goods in urban areas is a very complex undertaking and carries with it broad responsibilities that are not common to other governmental activities. It affects the life and activities of over 2/3 of the National population. It will require a great deal of cooperation and administrative teamwork, not only within the staff of a particular city, but between cities in a metropolitan area, the State Highway Department, and the Federal Government. The work of the National Committee on Urban Transportation has attracted considerable interest. It is firmly believed that its program has a great potential and, if followed, will provide a common factual basis upon which local government officials in urban areas can build an effective program to solve their transportation problems in a more efficient manner and for the benefit of all concerned.

Relations Between Public Agencies in Carrying Out the Program

Having determined the general overall traffic need requirements, methods must now be devised to effectuate this plan within a reasonable time limitation. This is not an overnight process. The Federal program provides for a 13-year period of financial contributions for the Interstate system. The new Federal Highway Law also includes a provision in that, it is the declared policy of Congress to include the other Federal systems in this same period for programmed completion. Some such period could be selected to complete a city's major program of urban expressways and thoroughfares. Since the work must be done in stages, and must be correlated with the Federal Aid contributions, a city's program can well be established along the same lines. Priority schedules will have to be worked out with the traffic costs and needs serving as a base for the establishment of the program. Since expressway construction in urban areas is very costly, and since Federal Aid is distributed only through the State Highway Departments, realistic programs can only be arrived at by complete cooperation between the cities and the state. Here, an effective liason must be established between these two agencies. Since the cities will, in many cases, cooperate with the state in furnishing the local matching funds, it is essential that the ability of each of these agencies to furnish their portion of the matching funds be taken into account. This will involve examination of the city's capital improvement program and of their financial status and tax base over a period of years in the future. State legislation, as it affects highway construction and financing, must be thoroughly examined. In many states this legislation must be revised, modernized, and updated.

Since financing is a major factor in the entire program, a careful scrutiny of financing is in order. It is commonly known that at both the national level and the state level, highway funds are derived from highway users, and the funds are intended to be used for highway needs. It is also known that the bulk of highway users live in urban areas, and therefore, the bulk of highway revenues originates in urban areas. In addition, every factual study made indicates that the origin and destination of the majority of vehicular trips lies within and around the metropolitan areas and the cities. Accordingly, it is reasonable to expect that the proper ratio of the highway user funds should be returned to the urban areas. Some states, within recent years, have acknowledged this principal and have returned a part of the state-raised highway revenues to the cities. In this matter, they are simply assuming their proper responsibilities. In turn, these cities have cooperated with the State Highway Department in financing the major highway improvements within the urban areas. Many other states must face up to this important fact, since matching funds must be provided in order to obtain the Federal funds.

Once these matters have been cleared, the next step must be taken which will lead towards the eventual construction of these major facilities. Discussions and conferences must be held with the appropriate State Highway officials in order to arrange a realistic and practical plan. The cities must be able to justify the request for the construction projects on a factual basis. The relative needs of the individual metropolitan areas must be emphasized and be highlighted to the state authorities. It is essential that distribution of available funds be made on a needs basis throughout the state and on the basis of the requirements of the individual metropolitan areas. Once these

facts are brought to the attention of the proper state authorities, it will be in order to discuss agreements between the state and the city for the construction of these projects. These agreements may be very general, but all-inclusive, with sufficient latitude in the agreement to develop details at a later date. Specific projects may be included in the agreement, and specific matters may be discussed concerning financing arrangements and timing of the projects. Once these matters have been thoroughly discussed between the agencies, and mutually agreed upon, these agreements may be reduced to writing and included in a written contract.

It will then be necessary to place this contract into operation. In order to avoid misunderstandings and complications, we have found that, in our own community, these matters are best resolved in a spirit of complete cooperation. A sympathetic understanding of the problems can be achieved if these matters are worked out on a joint basis. Accordingly, in our city, for the construction of expressways, the method adopted was a committee form of discussion. Since our city, population-wise, is a large part of the county in which we are situated, and since our state laws permit the county to participate with the city on state trunkline projects, both financially and otherwise, arrangements were made to include and to request the active participation of our county in our problems. At the inception of our expressway program immediately after World War II, an overall agreement was entered into between our State Highway Department, our County Road Commission, and the City, to construct two expressways in the city, some 25 miles in length. This agreement, among other things, provided that all parties would mutually plan the projects and approve all working plans prior to construction.

A committee was formed of engineers representing the State Highway Department, the County, the City, and, in addition, the Bureau of Public Roads, since the plans would eventually be submitted to the Bureau for their approval prior to their participation in the projects. Each of the parties was represented on this committee, to pass upon all matters governing location, design, construction, timing, and all other policy features involved. A technical sub-committee, reporting to the major engineering committee, was also created to work out the various details. The sub-committee consisted of engineers representing all phases of the work involved, such as location engineers, planning engineers, traffic engineers, bridge engineers, road engineers, construction engineers, right-of-way engineers, and any others that might contribute technical advice and information. In turn, further sub-committees were called upon, from time to time, involving specific matters pertinent to construction in an urban area. This included public utilities, both privately and publicly owned, transportation experts, police and fire personnel, railroad engineers and operating personnel, land buyers, real-estate advisors, and attorneys.

These committees met at very frequent intervals to work out the various problems that would be encountered in a project involving the laying out, planning and construction of major expressways in an urban area. It will be appreciated that in laying out a project through a densely developed city, there will be many problems involving the approval of route locations, acquisition of property, dislocating and relocating residences, businesses, and industries. The type of expressway built in our city requires a right-of-way from 300 to 350 feet wide on a new location. This required the rearrangement of many large sewers, watermains, lighting and power facilities, large trunkline telephone cables, overhead and underground lines of all types,

the construction of suitable traffic detours, and the permanent rearrangement of traffic patterns.

Arrangements had to be made, among the parties, for actual preparation of the final plans. The efforts of all agencies had to be pooled, drawing on all their technical advice, information, and personnel, in order to arrive at the stage of final plans and of the placing of the work under contract. The work of preparing plans, and the various responsibilities of carrying out the construction, was divided among the agencies best prepared to do so. This, of course, was all done under the direct supervision of the State, since, by law, our State Highway Commissioner has complete jurisdiction and responsibility for all State trunkline improvements. But, by designating certain units of government as agent for the State, the work was completed in the most effective manner and in the shortest possible time. Thus, the State handled one project in its entirety, insofar as bridge and road plans were concerned. The county likewise assumed this responsibility on a second route, and the problem of utility plans was handled in a separate manner.

Because of the pecularities of a large city, underground installations are a major problem. The preparation of plans, specifications, and cost estimates for the relocation and reconstruction of city-owned utilities was delegated to the city utility departments. It was determined at the outset that these agencies were best qualified to prepare such plans for their inclusion in the final contract plans. They are best qualified because they have the most reliable information available regarding their own installations. In many cases, additional design and drafting aid had to be provided for these agencies through the use of consulting engineers, but the original planning and design of the work was prepared by these utility agencies themselves. In order to best perform this service, each of the city departments preparing plans was requested to establish a permanent group in their agency who would devote full time to this work. Thus, the expressway planning was divorced from their routine work and could be given their fullest attention. This procedure applied also to specific groups in the city planning agency, in the traffic engineering bureau, and in the department of public works, in order to accelerate the planning arrangements. In the case of the privately-owned utilities, the same procedure was followed. They, too, are best qualified to plan and to supervise the reconstruction and relocating of their facilities.

Coordinating of this plan preparation, and of the construction schedules, in order that all stages of the work are done at the proper time and in the proper sequence, is a very important part of this problem. Again, joint efforts and pooling of knowledge and talent, and the anticipation of the problems involved wherever possible, will accomplish the results desired.

In order to avoid duplication of efforts and the problem inherent in large communities, final results and determinations were left to a very small coordinating committee composed of one member from each agency devoting full time to the project. The State, the County, and the City each appointed a major department head as their expressway coordinator. Our City appointed its Commissioner of Public Works as the City's coordinator. In turn, the city established a separate Expressway Division within the Department of Public Works, to handle all expressway problems involving the County and the State, with an Expressway Engineer serving as full time coordinator between the various city departments, and as a liason with the State and County. Since there are a considerable number of operating departments within a city, all of their particular problems had to be reconciled in order to

accommodate the expressway construction. In many cases, practices and policies of long standing in a city may have to be changed. Governmental red-tape, normally a very irritating and annoying matter, must be overcome. Otherwise, progress cannot be achieved. A method must be found to eliminate, as much as possible, this governmental red-tape. In a large city, many of the individual public agencies are jealous of their prerogatives, responsibilities, and their duties. These have usually been established over the years by the necessary requirements in heavily congested areas, and because of the precautions to be taken concerning the public health, the public safety, and the public welfare. How to eliminate this red-tape is a problem that has no ready answer. Many compromises will have to be made between the various parties and the various individual agencies; but, for the common good, these compromises must be made.

By a cooperative attitude between these coordinators and often times working in unison, the many problems that arose were resolved. Frank discussions with the many agencies, well in advance of the immediate problem, and with some give and take on the part of all parties, usually resulted in a satisfactory solution. The coordinator for a city must have rather wide latitude, considerable authority, and responsibility to carry on the work. This will require cooperation, encouragement, and approval from the legislative and administrative branches of the city government. In addition, the same attitude must prevail at the level of the other agencies involved.

At the city level, it will be found that the best results will be obtained if those agencies, most interested in highway development, will cooperate and prepare their plans well in advance. Again, a committee type of discussion is found workable in our city. Thus, we have developed a small committee consisting of the Department of Public Works, working through the Expressway Division, the City Plan Commission, and our Traffic Engineering Bureau. This committee considers and examines very thoroughly all matters relating to highway improvements and the construction of expressways and freeways. Preliminary plans are developed well in advance of discussions with the State. In this way, the City is enabled to present requests for suitable and acceptable projects which have been agreed to by the city as a whole and in which all important factors involving the city will have been considered. Thus, all problems affecting city planning, traffic engineering, construction, and financing are known in advance and can be submitted as the city's accepted program.

The problem of sound public relations cannot be ignored. The general public, which pays for all these improvements, must be given every consideration. They have a right to be heard, and a right to understand how the program will affect them, and how they are involved. By marshalling all the facts and information, and by a sympathetic attitude and treatment of the taxpayer, their aid can be enlisted for the benefit of the program. On the other hand, it will often be necessary to overcome the actions of self-interested pressure groups. In this matter, the interests of the City as a whole should be paramount. It is important to know that in constructing expressway projects in densely developed areas, the people, the business interests, and the industries will suffer untold, but necessary, inconveniences. They must be given sufficient notice of the intentions of the public agencies. They must be given time to relocate their homes, their businesses, and their industries, and they must be treated fairly. It should also be understood that heavy construction, such as expressways and freeways, will cause innumerable

problems to the city as a whole, and particularly to abutting properties, because of the movement and use of large pieces of equipment and machinery, and the problems inherent when handling large volumes of earth excavation. Tne matter of air and street sanitation and cleanliness during the construction periods, and of traffic dislocation, both through residential and commercial areas, is not to be ignored. While this is a transitory problem, it is very real to the abutting property owners and those most intimately concerned. A city must make every effort to minimize these problems and to consider the attitude of the general public in these matters. It is here that the patience of all persons connected with such a program, both public and private, will be tried to the utmost.

In regard to the expanded program ahead, and in which cities must take the initiative, it is foreseen that more efficient procedures will be required. The methods necessary to arrive at original planning and layout, final plan preparation, and construction, can be refined. In many cases, considerable streamlining of procedures is in order. Methods must be devised to eliminate cumbersome details which have no major effect on the program. Also, ways must be devised to minimize the rigidity of procedures and methods that have accumulated over the years in our public agencies. Simplified plan preparation is inevitable if the program is to be accelerated. Simplified procedures in the balance of the construction processes must also be instituted. This will apply to contract letting, and relations with the contractor. Considerable clarification will be needed in the application of the laws at all levels of government which deal with this type of construction. It is urgent that urban representation be established in State Highway Departments and in the Bureau of Public Roads in order to more effectively deal with the problems in urban areas. These urban units must be full-time personnel, and acquainted with the problems and with a sympathetic attitude towards the cities. In general, the relationship of this urban representation, both at the policy level and at the level of local contact, must be expanded. It is generally known that in many instances there are several ways of preparing a plan, a report, a specification, or of interpreting technical considerations, all equally satisfactory. The requirement that these things be done in a rigid pattern-like manner, in order to meet the requirements of bureaucracy, should be eliminated. Otherwise, the entire program will be retarded. This can be accomplished when all parties reach a complete understanding and realize that the program is to build acceptable highways in the shortest possible time. There is no question that the work can be done without sacrificing either economy of construction, good workmanship, or sound principals of engineering.

Thus, for the cities of the Nation to find their proper place in the expanded highway program, it will be necessary that they consider these important steps: (1) They must make a realistic and practical appraisal of their street and highway needs at the very earliest opportunity, based on a workable overall city plan, and (2) They must reach satisfactory agreements with their State Highway Departments to finance and construct their needed highway facilities on a factual basis. They must develop simplified methods and procedures for accelerating the program in conjunction with all other public agencies with which they deal. They must appreciate the value of good sound public relations since in the final analysis it is the public who pays the bill for all these improvements. In the interest of better government, in the interest of an expanded highway program, and for their particular immediate benefit, the cities must pursue this program with vision, with fortitude, and with courage.

Paper 1372 September, 1957 HW 4

Journal of the
HIGHWAY DIVISION
Proceedings of the American Society of Civil Engineers

DIRECT SOLUTION FOR TRIPLE SPIRALED COMPOUND CURVE

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(Proc. Paper 1372)

The analytical solution presented in this paper is believed to be somewhat shorter and more fundamental than the traditional solutions. After the tangent distances of the unspiraled compound curve have been computed, all that remains is a few easy calculations which may usually be done by slide rule with sufficient accuracy.

By any of the customary methods the computation of the tangent distances for a triple spiraled compound curve is a long and tedious job. The analytical solution presented in this paper is believed to be somewhat shorter and more fundamental than the traditional solutions. The work involved is only slightly greater than that required to calculate the tangent distances of an unspiraled compound curve, and the method of attack is sufficiently logical and fundamental so that anyone with an understanding of a simple spiraled curve can easily apply the method with confidence, and without recourse to special formulas. However, two formulas are derived and presented for the benefit of those who wish to get an answer rapidly, with a minimum of time and effort.

The spiral function notation used in this paper is illustrated in Figure 1. 0 is the distance that an unspiraled circular curve is shifted inward, perpendicular to the tangent, in order to accommodate a spiral. 0 is also the distance that a sharp circular curve is shifted inward from a flatter circular curve in order to accommodate a spiral between the two circular curves. The tangent in Figure 1 is merely a special case of a flat circular curve with a radius of infinity. Z is the distance measured along the tangent from the TS (or ST) to a point opposite the offsetted TC (or CT). In other words, 0 and Z are a pair of rectangular coordinates which locate the offsetted TC (or CT). In many cases 0 and Z may be picked directly from spiral tables. In the

Note: Discussion open until February 1, 1958. Paper 1372 is part of the copyrighted Journal of the Highway Division of the American Society of Civil Engineers, Vol. 83, No. HW 4, September, 1957.

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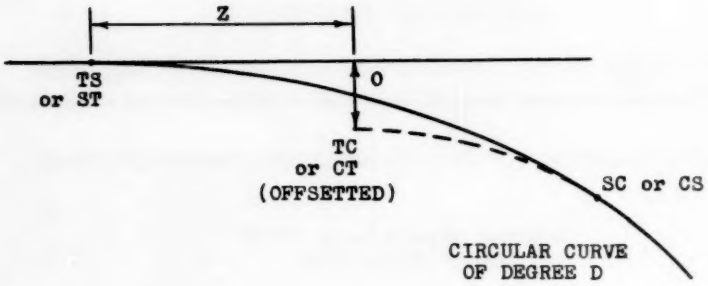

FIGURE NO. 1. SPIRAL NOTATION

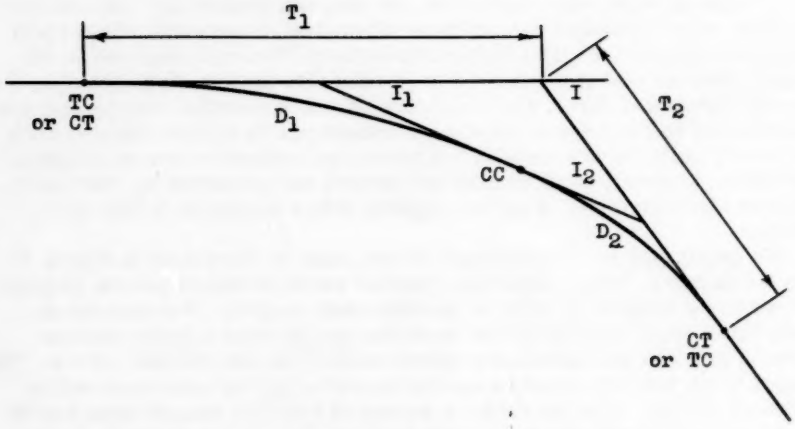

FIGURE NO. 2. NOTATION FOR COMPOUND CURVE
WITHOUT SPIRALS

absence of tables both 0 and Z may be easily calculated if the length of the spiral, and the rate of change in the degree of curvature of the spiral, are known. 0 is a relatively small quantity which may be computed with sufficient accuracy by slide rule, in most cases. Z is equal to one-half the length of the spiral minus a small correction which may also be computed by slide rule with adequate accuracy. For further details the reader may consult textbooks on Route Surveying.

The compound curve notation is illustrated in Figure 2, which shows a compound curve of central angle I; and curves of degree D_1 and D_2, having corresponding central angles I_1 and I_2. The tangent distances of the unspiraled compound curve are T_1 and T_2, as indicated; T_1 being adjacent to D_1, and T_2 being adjacent to D_2. T_1 and T_2 may be readily computed using ordinary compound curve theory. In applying the method which follows it is important to note that the flatter curve has the degree D_1, and the sharper curve has the degree D_2.

In order to accommodate the three spirals the circular curves of degree D_1 and D_2 are offsetted from each other, and from the tangents, as illustrated in Figure 3. The offsets 0_1, 0, and 0_2; and the distances Z_1 and Z_2, are all familiar spiral functions which may be computed independently, as previously discussed. The tangent distances of the triple spiraled compound curve are Ts_1 and Ts_2.

According to Figure 3:

$$Ts_1 = T_1 + Z_1 + F_1$$

and $$Ts_2 = T_2 + Z_2 + F_2$$

The primary purpose of this paper is to show how F_1 and F_2 may be easily determined by visualizing the offsetting as consisting of three independent shifts. Each shift is a pure translation. At all times the circular curves maintain their initial angular orientation with respect to each other and to each tangent.

Shift No. 1

First of all both curves, as a unit, are shifted the distance 0_1, perpendicular to the tangent T_1, as illustrated in Figure 4. From the small right triangle A it is clear that the first shift causes the CT to move parallel and perpendicular to the forward tangent by the amounts $0_1 \sin I$ and $0_1 \cos I$, respectively. (If the sharp curve, of degree D_2, were adjacent to the TC, then the first shift would be perpendicular to the forward tangent instead of the back tangent; and the small triangle A would be adjacent to the TC instead of the CT. The same is true for triangles B and C, which follow.)

Shift No. 2

Secondly the curve of degree D_2 (the sharp curve) is shifted inward the distance 0, perpendicular to a tangent at the CC, as shown in Figure 5. From the small right triangle B it is evident that the second shift causes the CT to move additional distances parallel and perpendicular to the forward tangent. These additional distances are $0 \sin I_2$ and $0 \cos I_2$, as illustrated.

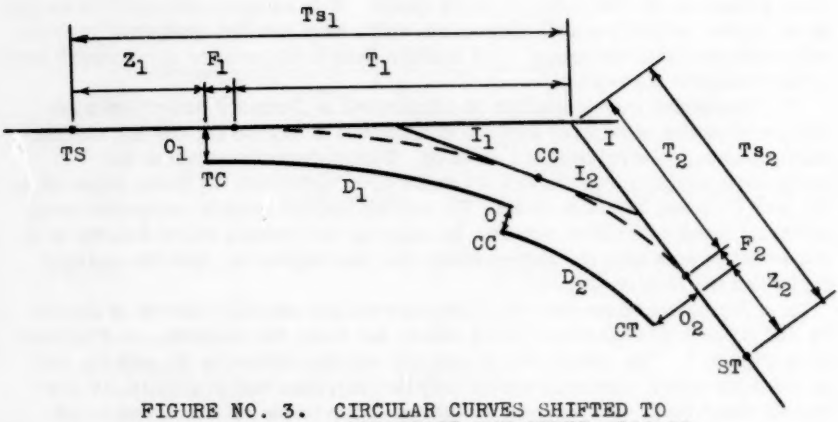

FIGURE NO. 3. CIRCULAR CURVES SHIFTED TO ACCOMODATE THE THREE SPIRALS

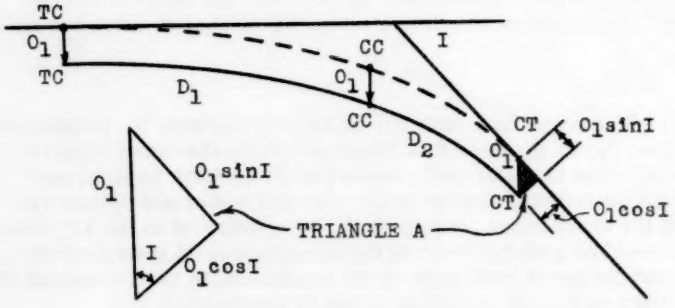

FIGURE NO. 4. SHIFT NO. 1

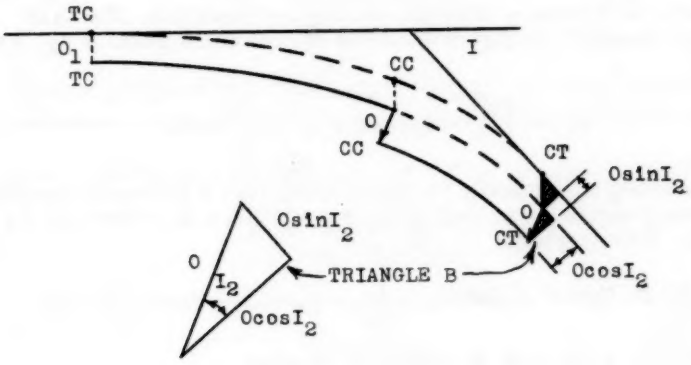

FIGURE NO. 5. SHIFT NO. 2

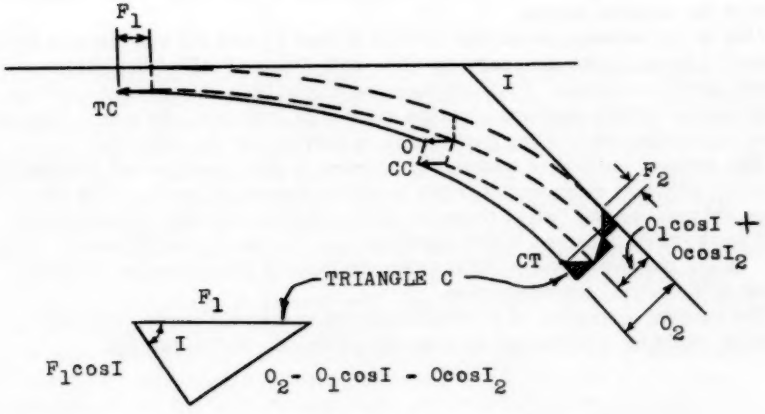

FIGURE NO. 6. SHIFT NO. 3

Shift No. 3

Finally, without changing 0_1 or 0, both curves are shifted as a unit through the distance F_1, parallel to the tangent T_1. F_1 is the amount of shift necessary to make the CT end up offsetted the required amount 0_2. The third small right triangle C, in Figure 6, may be solved for the distance F_1. From triangle C:

$$F_1 = \left[0_2 - 0_1\cos I - 0\cos I_2\right] \csc I$$

Now, by adding algebraically the amounts that the CT has moved parallel to the forward tangent, as a result of the three shifts, it is evident that F_2 is obtained. From Figure 6:

$$F_2 = 0_1\sin I + 0\sin I_2 - \left[0_2 - 0_1\cos I - 0\cos I_2\right] \cot I$$

or $$F_2 = 0_1\sin I + 0\sin I_2 - F_1\cos I$$

Referring back to Figure 3 it is seen that F_1, Z_1, and T_1 must be added algebraically to get Ts_1. Likewise F_2, Z_2, and T_2 are added algebraically to get Ts_2. Both F_1 and F_2 will usually be positive but either one may be negative, depending on the relative magnitudes of the three offsets and the size of the central angles.

One of the advantages of this method is that F_1 and F_2 may usually be calculated with adequate accuracy by slide rule, because all of the terms involved are quite small. Civil engineering students in the writers classes have solved typical problems by this method in less than one hour. The most time-consuming part of the problem is in solving for T_1, and T_2.

The general method of analysis presented in this paper is not limited solely to the problem of solving a triple spiraled compound curve. Any one of the three spirals, or any two of them, could be omitted and the method would still work; certain terms in the equations for F_1 and F_2 would merely drop out. In the same way the method gives the tangent distances for a simple curve with unequal length spirals.

The tangent distances of a three-centered compound curve, with four spirals, could be determined by a direct extension of this method.

Paper 1373 September, 1957 HW 4

Journal of the
HIGHWAY DIVISION
Proceedings of the American Society of Civil Engineers

HOW TO INCREASE THE PRODUCTIVITY OF HIGHWAY ENGINEERS

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(Proc. Paper 1373)

SYNOPSIS

There are three vital factors with which State Highway Engineers must concern themselves in increasing the productivity of their staffs; namely, personnel engineering techniques and morale. The effect of these factors are described and evaluated.

The new National Highway Program will throw such an unprecendented burden on state highway departments as to require all highway engineers to provide the most effective means for working out the engineering problems and developing the contract plans and specifications in time to get construction under way. The demands which they all will have to face in this new program will be tough, for the highway engineers will have to produce a finished product with depleted technical staffs, and inadequate salaries. To counterbalance these difficulties, the supervising state highway engineers will have to exhaust all efforts in order to increase the productivity of their staffs while maintaining a high degree of engineering quality in the final product on which contractors are to submit bids.

How can this be done? It can be done by "banging" away at those important factors which will produce tangible results. There are three vital factors with which the supervising state highway engineers must concern themselves in increasing the productivity of their staffs; namely, (1) Personnel: sufficient men must be recruited to do the engineering and develop contract plans; (2) Engineering Techniques: engineering time must be saved by using new methods which will make the most of engineering manpower; (3) Morale: consideration must be given to the hopes and desires of the engineers producing the work. The desire of the engineers to produce more and better work must be improved.

Note: Discussion open until February 1, 1958. Paper 1373 is part of the copyrighted Journal of the Highway Division of the American Society of Civil Engineers, Vol. 83, No. HW 4, September, 1957.

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Of the three vital factors mentioned here, the most important one is "personnel." Without men to do the work, the engineering and the preparation of contract plans cannot be done. No matter how many " electronic" brains the supervising highway engineer may have at his disposal, if he does not have the engineers in the drafting room to do basic work, he will never be able to develop designs and produce contract plans. For this reason, realistic thinking in personnel techniques must be exercised in the highway organization. If the highway engineers are to see to it that "personnel" does not become a critical problem and a stumbling block in meeting deadlines in the development of designs and plans, the highway organization must then concern itself with an emphasis on those techniques which are directed toward recruiting employees, classifying them and determining their compensation, and training them. To make sure that the highway program will not bog down, every one of these personnel techniques should be accentuated and if necessary, fought for relentlessly in those areas where legislation is required to carry them out.

To handle these personnel problems and techniques effectively, the highway organization will experience many advantages if it has its own central personnel agency. The Highway Research Board Special Report No. 20, indicates a number of states which do not show a personnel agency within its own organization. The advantage of a highway personnel agency within its own ranks is that the personnel specialists become closer to the highway employees and more familiar with the operating problems of the highway engineers than the central personnel agency of the state.

With reference to the technique of recruiting highway engineers, it should be said that getting qualified persons into the highway engineering service cannot be accomplished in a hit-or-miss fashion. An essential element of a recruiting program is advertising employment opportunities. It pays to advertise employment opportunities just as it pays to advertise to promote any product. The challenge of this new highway program cannot be met by sitting by, expecting young engineers and experienced engineers to apply for positions in the highway field. These engineers must be won from their present ambition and occupation and encouraged to enter the highway engineering field. One effective method is advertising the employment opportunities through personal contact. In recruiting young graduates, a personnel officer of the highway organization should be allowed to "scout" various colleges and talk personally to prospective graduates about the many opportunities in the field of highway engineering. The highway work should be dramatized to the young graduates if engineers are to be obtained to do the job. This technique is employed quite commonly in private business. Years ago, young college graduates used to come to the highway engineers for employment. Now in this new era, the highway engineers must go to the campus and sell them their type of engineering.

A second effective method in recruiting engineers, which has been used successfully by many jurisdictions is to encourage local newspapers to run periodically, news stories on the activities and employment opportunities of the highway organization.

Now, by making use of these methods, particularly the former, the highway organization will make great strides in accomplishing the objectives of its activities.

The second personnel technique which the highway organization should concern itself in this new program is that of classification of highway engineers

together with their compensation. Most highway departments are under a civil service system. In this new highway program, it is not enough to have all the duties of highway employees classified into an orderly occupational inventory known as the "position-classification plan." The plan must be continuously modified to keep it up to date; and means must be established for keeping abreast of changes in the nature of duties and conditions.

When the classification standards are controlled by an overall Civil Service Commission or agency at the state level, the highway organization should have in its highway personnel agency classifiers who will represent the highway engineering interest and suggest to the state civil service commission changes in the position standards, which would permit the highway organization to function more effectively and carry out its responsibility in this unusual program of highway improvements. Position classifiers are just as necessary in the Highway Organization during this big highway program as are the legal counsels. Like highway attorneys, the position classifiers can often discover ways and means of reclassifying positions upward and still satisfy the position and class standards of the Civil Service Commission. The Highway Department of the District of Columbia has had classifiers in its highway organization for more than ten years; and they have done a magnificant job in raising the salaries of the highway staff as to make the D. C. Highway Department among the upper third in the average salary bracket of all states with some of the key positions being fifth and sixth in the salary bracket of state highway officials. Yet, in area, it is the smallest jurisdictions included in the Federal Aid System.

There are a few engineers who can consider money earned on the job as of secondary interest; for most of them, the matter of earning a living for themselves and their families is a serious business. The salaries paid to highway employees will probably be the most important factor not only in retaining their present staffs, but also in attracting a sufficient number of engineers to help them meet the demands of the highway program. Good salaries can often be realized through classification techniques in which a classifier is a specialist. So, it is very important that the highway organization have classifiers on their staffs to assist in attracting employees to do a complete job under this highway program.

A third personnel technique which should be emphasized in this new highway program is employee training program. The need for training has long been accepted by large companies and corporations. It is only in recent years that highway departments have recognized the benefits of an organized training program.

If we are to meet our responsibilities in the engineering and preparation of plans in this new program, a training program should be set up to provide a reservoir of personnel not only to take care of the normal turnover in the highway organization, but also to provide for expansion to meet the requirements of the new highway program. There are two types of training programs which could be set up in the highway organization, namely:

1. Training of "Interns."
2. Training of highway engineers for future administrative positions.

With reference to "Training of 'Interns'," it can be said that to secure a fair share of college graduates for highway employment is not merely a matter of active recruitment. The highway departments must be prepared to

receive them, to give them constructive practical experience to supplement their academic training and to make possible careers for them that can compete in attractiveness with the careers offered by private industry. This can be done by setting up a program whereby raw material is recruited from various engineering units of the highway department in order that these trainees may be trained sufficiently in all basic activities to which the program is later to feed personnel. In other words, if the training program is to provide a reservoir of personnel for future permanent appointment in any one of organizational units of the highway department, the trainees should then be exposed to such activities as the construction activity, the inspection activity, the field party activity, highway design activity, bridge design activity, etc. However, in doing so, the intern trainee should not be used (if possible) to fill an existing vacuum in any one activity. He should be considered as a desirable "surplus." In other words, if a project needs three inspectors to fill the needs of the project, a fourth inspector (a trainee) could easily be added advantageously.

To make the program successful, the highway department should make each recruitee a definite commitment as to the magnitude of his salary at the end of the training period as well as to possibilities for advancement; otherwise the program might slow down because of lack of enthusiasm.

Relative to Training of Highway Engineers for Future Administrative Positions, it can be said that, in the development of plans and engineering, one of the vital tasks in directing the program is to attract and retain personnel who will supply effective management for current operations and from whom the key administrative engineers will be drawn in the years to come. Any plans that will aid in the accomplishment of that end will surely pay for themselves many times over. How can the successful administrative engineers be recognized in advance? Despite the great technical skill of an engineer, his ability to serve strictly in the various administrative levels of the highway organization might be deficient. Many engineers of high intelligence and practical competency often turn out to be ineffective when placed in strictly administrative positions. It is not that these engineers do not know their engineering or lack the technical skills. It is rather in the area of their relations with others on the job and their aptitude towards exercising "command," "coordination" and "control." So, great benefits can be derived from a training program which provides a pool of prospective administrative positions. The Bureau of Ships of the Navy Department has such a training program which is very effective in preparing men for top administrative positions.

Now the personnel agency is an auxiliary agency and it exists primarily to provide specialized services to the operating units of the highway organization. It can only be justified to the extent that it contributes to the accomplishment of the major purposes of the highway organization. In other words, there is no point in setting up a host of personnel specialists unless they further the efficiency of the various operating units of the highway organization. However, a progressive personnel group in the highway organization, which is able to feel deeply the needs of the supervising highway engineers in meeting schedules and deadlines and which is constantly emphasizing the personnel techniques which industry has long proved effective will go a long way towards solving present personnel problems, which now exist in the majority of highway departments. However, merely because such a central personnel exists in the highway organization does not mean that department heads and supervisors must forget about personnel problems. To the contrary,

personnel administration must be a major concern of the administrative staff from the chief administrator all the way down to the first line of supervisors. Supervisors must still handle certain personnel aspects of their respective activities and assume a responsibility in personnel problems. Since they are closer to the employees and more familiar with their problems than the personnel agency, they should also play an important part in the formulation and in the execution of personnel problems and standards. For years, it was not recognized that employees should have any part in the formulation of personnel program. Recently, private industry and many governmental jurisdictions have developed a growing appreciation of the contributions which employees can make in getting modern methods of personnel management accepted.

Now it has been mentioned earlier that personnel is the most important factor in getting the plans and engineering done in this new highway program. If, in spite of all these techniques which have been discussed, sufficient number of engineers cannot be obtained to do the job, the highway organizations should seriously consider doing what the Highway Department of the State of Kentucky and the Bureau of Ships of the Navy Department are doing at the present time, that is; finance out of their own funds engineering scholarships to promising high school graduates with the agreement that the recipients will work a number of years after graduation in the highway department financing such scholarships. This, perhaps will require legislation to carry such a program. However, it is being done at this time and it should be done if shortage of engineers continue to develop.

In summary with respect to this factor of personnel, it should be said that unless good personnel methods are accentuated in the highway organization, the new highway program will be seriously handicapped. For this reason "personnel" should be the most important factor in the highway engineering activity.

The second vital factor which should be of concern to the supervising highway engineers responsible for the plans and engineering is the factor of Engineering Techniques. This can be divided into two classes; namely,

1. Increased productivity of the engineers.
2. Progressive Engineering.

At the present time a great deal is being said about adopting new production techniques designed to ease the work load of designing engineers. Highway Engineers are all conscious of the fact that unless they concentrate on increasing engineering productivity they will be faced with the dilemna of having incompleted plans with funds to be obligated.

One of the most "talked-about" time saving devices in the engineering field is the electronic computer. Many states are using this computer at a reduction of manpower requirements. The electronic "brains" are used in many jurisdictions to make traverse and earth work computations; to check the unknown bearings, distances or areas; to compute simultaneous equations; to calculate quantities of steel by bar sizes for bridges; and to figure out physical properties of indeterminate structures together with the computations of moment and shear values. The bridge department of the State of California is concurrently writing the procedure for the design of composite beams in bridge structures. All these applications of the electronic computers have released many engineers for more skilled work, and for this reason, highway engineers should all prepare and train their staffs to make wide use of the electronic computers. They should not hesitate to have their engineers attend

classes at electronic computing schools to learn how to prepare "programs" of their own activities for the electronic machine. The Highway Department of the State of Georgia has had twenty men attending such classes in order that they may endeavor to adopt the computer to their numerous problems.

Another very important time saving method in the preparation of plans is the use of design manuals for the designers. The purpose of such manuals is to formulate methods to be followed in the design of routine highway problems. Sometimes many manhours can be wasted by the designing staff either in the selection of the mathematical approach to the solution of a problem or in the checking of the final solution to the same problem.

Furthermore, the design manual saves a great deal of time in getting new personnel acquainted with the accepted method used by the particular design agency in the solution of problems. The design manual also saves engineering time in outlining a well organized tabulation method and procedures in developing mathematical analyses. It is a good control tool in the in-service training of engineers. Many private engineering firms have long made use of design manuals because they have recognized manhour savings of which they are very conscious. During the last war, the aircraft industry has received a great boost in engineering efficiency from the use of such manuals. The Bureau of Yards and Docks have a very thorough design manual which also goes into the design of various types of foundation. There are many states which have such manuals. If a highway department does not have such a manual, it is indeed worth the investment to detail a full time engineer in the preparation of such a manual.

A third important time saving device is a Highway Department Procedural Manual or guide book. A great deal of time is often wasted in the design and engineering organizational units of a highway department because of lack of understanding of procedures to be followed in processing papers, designs, estimates, letters, etc. Such a manual should be made available to all employees and should delineate specific details of departmental procedures and routines as well as outlining the successive steps to be followed in processing work. Such a manual should also delineate the functions of various units of the highway organization. For instance, such a manual could outline "Who initiates the recommendation of change orders in highway contracts; what division should review such change orders; who approves such change orders." Or the manual could outline what engineer writes what letter and to whom.

If the highway organization does not have a Procedural Manual, it should immediately undertake the task of preparing one because a great deal of time saving can be effected by such a manual through the elimination of misunderstanding and confusion among the highway employees. In order to save engineering manpower, the management group of the highway personnel agency could be assigned the task of preparing and publishing such a manual.

A fourth time-saving device is the use of standard drawings for both roadways and bridges and also streamlining the plans by eliminating duplication of details. In roadway design, standard curb details, standard roadway slabs and subgrades, standard wall designs, standard inlet designs could be worked out separately on standard size tracings which could be reproduced and incorporated in each contract set of drawings issued to bidders, without having to work out these details over and over again.

In bridge design, standard drawings can be worked out for walls, bearings, retaining walls, retaining walls on piles, railings, sliding bearings, rocker

bearings (I Beam Structures), rocker bearings (Prestress Structure), and expansion dams. Figure 1 shows a typical wall design detail which is incorporated in all District of Columbia bridge contract drawings. This typical wall design eliminates the necessity of having the engineer design or detail these walls over and over again for each bridge put under contract. In this manner, a great deal of engineering time is saved. Now these standard details may be eliminated from project contract drawings by including them in mimeographed special provisions of the project specifications. The Bridge Division of South Carolina follows this latter procedure.

Another time saving device in the preparation of contract plans is the use of pencil tracing and have photographic processed linen reproductions made from pencil drawing after construction. This method also is a saving in the cost of preparation of plans. In Washington, D. C. area, as much as $60 per sheet of drawing can be saved.

Now in the preparation of standard designs or standard design details, good judgment has to be exercised on what feature should be standardized. In the Highway Department of Georgia, the average mortality rate of standard drawings is approximately four years; and one feature which has contributed to the obselescence of standards has been certain changes which have occurred in the method of computing load distribution and the gradual upward trend in allowabel design stresses. So, the time saving aspect of every design feature should be properly appraised as to its worth before developing standards for same. For instance, substructure units are not readily adaptable to standard design. But many superstructure features could easily be standardized.

There is nothing which will increase the engineering time more than the design of structural facilities to fit some odd geometrics produced by the planning engineer. Many bridge engineers have appealed to the planning engineers to watch how they swing their pencils around when developing the geometrics of highways. Skewed bridges with superelevated roadways are time consuming facilities to design. To make planning engineers sensitive and cautious about developing complicated geometrics where structures are required, The District of Columbia placed, three years ago, a bridge engineer on the staff of the Planning Division which has the responsibility of developing geometric designs. If the state organization is of the type receptive to such an arrangement, it is recommended that a bridge engineer work with geometric engineers. It will save many mandays of bridge engineering work.

Now in carrying out their responsibility in this new highway program, highway engineers would be amiss if we did not endeavor to improve the engineering quality of their designing engineers. This can be done by setting up processes which will stimulate, educate and develop the engineers in order that they may excel in their own particular fields. This can be done by urging all highway engineers to affiliate with their respective professional groups; to attend conferences in their field of activity; and to read technical magazines. With reference to the last mentioned, the District of Columbia circulates certain magazines through various engineering units and insist that it be initialed by various engineers so that they will be at least exposed to the technical contents of these magazines.

Again, it should be said that the second most important factor with which the supervising highway engineers must concern themselves in effectively tackling this new highway program is that of good engineering techniques which will increase the productivity of the highway organization. Without

emphasis on these techniques which have been described will jeopardize highway engineers' chances of meeting schedules.

Now, the factor of "morale of employees" has been mentioned as an important factor which should receive serious consideration in the efforts to expedite the new highway program. Military experts know that a general who goes to battle with an army which has a very low morale has two "strikes" against his winning the battle. In this new highway program, how interested are the supervising engineers in improving the morale of their highway employees? Do they try to find out what their employees are thinking about; how they react to their leadership; whether they are expounding the philosophy of the highway organization the way every one of them would do if they were in their jobs. Every highway engineer who has been given the responsibility and authority of a supervisor at any one level must be completely sold on the thinking of the chief highway administrator and his personnel policies. An engineer may be one of the most conscientious highway officials, and yet find in some units of the highway organization unrest and deep feeling of personal animosity toward the whole highway department. In the great majority of cases, this rejection of the highway organization is caused by a lack of basic understanding of human relations on the part of supervising highway engineers at various levels. The importance of the human relationships in the various levels of highway engineering management cannot be over emphasized. Positive leadership plays an important part in all supervisory positions. It exhibits itself in the manner in which orders are issued, directions are given, training opportunities are afforded to the personnel, the types of procedures which are set up, the manner in which corrections and reproof for mistakes are offered, and the way in which staff participation is encouraged in the formulation of the objectives and the procedures of any highway organizational unit.

Following are some of the rules which the effective supervising highway engineer must understand:

1. Use of authority and the threat of discipline is one of the weakest tools of leadership. Because a supervisor possesses official authority, he should not expect unquestioning obedience of his subordinates no matter what orders he issues. If he endeavors to run his organization according to this notion, he will soon discover the "poverty of power." The morale of his staff will disintegrate when they are forced to execute commands which they believe incorrect. He will soon learn that there is a world of difference between obedience and active cooperation. It is the latter which will help the supervising highway engineers in meeting schedules.

2. Highway employees must understand the common goals of the organization. Before a highway employee can become an effective member of the organization, he must be given a picture of the highway program and its aims and purposes. He must feel that his own future is bound up in the future of the organization. Periodic meetings of the highway personnel should be scheduled, in which not only the ideas of the highway organization are communicated to the employees but also the goals and schedules are delineated. Many corporations and private companies schedule such informational gatherings for their employees. Meetings of this nature can be scheduled in sections so as not to disrupt the activities of the highway organization.

3. Praise is generally a more effective stimulus than reproof. A supervising highway engineer should not underestimate the power of rewards. Praise for work well done may give an employer as great a boost as a $100 raise. Of course, it is necessary sometime to reprimand employees; but such reproof should be done in private and anger should not be used to enforce corrective measures. When the loyalty of an employee is not in question, there should be few occasions for reproof. However, when insubordination arises from lack of loyalty, it should be treated firmly and promptly.

4. Subordinates must be delegated the broadest possible authority. It is important in this new highway program that all supervisors at various levels be permitted to make their own decisions for their own respective organizational units, within the widest possible limits. The technique of delegation is one which most engineers find extremely difficult to acquire. It is true that, if final authority to make decisions in certain areas are delegated to engineers far down the supervisory line, they may sometimes make mistakes that will embarress many high level supervising engineers. It is equally true, however, that the latter will sometimes make mistakes in their own decisions, so the possibility of error is no argument against delegation. Any supervising engineer who assumes that his job is to correct the errors made by his subordinates imposes on himself an impossible administrative burden, and encourages in his subordinates an entirely negative "error-avoiding" attitude toward their work. There is nothing which will add more to improving morale of a highway organization than to make each member a "self-starter," sincerely devoted to the aim at the smallest organizational group to which he belongs. Employees and supervisors who are interested in group objectives and loyal to their superiors will develop desirable working habits with a minimum of supervision.

5. An Employee Incentive Award Program should be set up. The morale of a highway organization can be greatly improved by encouraging all employees to submit suggestions in the improvement of every aspect of the highway engineering activity. One may say "why should an employee be rewarded for carrying out an outstanding task when it is his job to do so?" The answer is the top administrator is responsible for the morale aspect of his organization. If he wants good employee morale to exist in his organization, he should not hesitate to sponsor any program which will give the employees an incentive to improve their service and contribution toward the objectives of the department. Many large corporations have such employee award programs and they know how such programs add profit to their balance sheets. The District of Columbia has such a program; and many highway employees have won awards ranging from $10 to $500.

In summary on the factor of morale, it is evident that highway engineers must give serious consideration to the mental attitude of every employee of the highway organization. Methods must be developed to determine what this employee's hopes and desires are; what manner of individual he is; what makes him tick; and why he works in the highway engineering field.

Building the morale of the highway organization calls for a good human relations program. In that regard let me quote a statement made before a

convention at Miami, Florida by Willard E. Brown, Assistant to the Vice President of Judd and Detweiller:

> "The best human relations program is aggressive, not defensive. It is positive not negative. It is truth, not subterfuge. It is deeds accomplished and described, not convincing words alone."

In summary it should be said that without proper emphasis and understanding of the factors of personnel, engineering techniques, and morale, it is difficult to see how highway engineers are going to discharge effectively their responsibility in this new highway program. It is only by taking NOW the highway organization machinery, putting it into sound operation and applying its power along these factors mentioned here, that the highway engineers will be able to keep it in first-rate operating condition to carry the heavy load of the highway activities during the next thirteen years.

Paper 1374 September, 1957 HW 4

Journal of the
HIGHWAY DIVISION
Proceedings of the American Society of Civil Engineers

OPERATION OF URBAN EXPRESSWAYS

Joseph Barnett,[1] M. ASCE
(Proc. Paper 1374)

Urban freeways and parkways often break down at peak volumes, stopping all traffic. This paper explains the reason for such stoppage when caused by too great traffic density, suggests a procedure for analyzing traffic thereon, and proposes that traffic entering expressways be controlled so that volume is kept well below possible capacity to insure free movement.

The costliest highways per mile, first cost, maintenance and operations, are the freeways, parkways, bridges and tunnels in metropolitan areas. Several are breaking down repeatedly, i.e., traffic is stopped and capacity reaches zero. The breakdown invariably occurs when the highway is needed most; during morning or evening peak volumes or when large numbers of vehicles are transporting people to or from centers of recreation.

This paper outlines the causes of such breakdowns and suggests an investigation procedure which the writer believes will lead to a solution of the problem. The investment in these highways is too great to tolerate their breakdown during periods of highest use when such breakdowns can be avoided by a change in operating procedure.

Causes of Breakdown

Free flowing highways cease to flow at all for several reasons. The cause with which this paper is concerned, the one which results in frequent and more or less regular breakdowns is too much traffic; i.e., a density of vehicles so great that the highway has to operate at or near possible capacity as distinguished from practical capacity.

When a freeway operates near possible capacity all vehicles move at nearly the same speed, all drivers stay in line at nearly all times and average spacing of vehicles is low. There is no leeway in operation. In effect to use a structural analogy the structure is loaded to a point near the elastic limit and any additional load or a redistribution of the load to cause any part of the

Note: Discussion open until February 1, 1958. Paper 1374 is part of the copyrighted Journal of the Highway Division of the American Society of Civil Engineers, Vol. 83, No. HW 4, September, 1957.

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structure to be stressed beyond the elastic limit causes failure. There is no factor of safety left under such conditions of load.

On a one-way roadway, half of a divided highway, operating at or near possible capacity the load, or traffic volume, is so near the limit of capacity that any additional load, or traffic volume, trying to use the roadway will result in complete failure or inability to accommodate any traffic. Such failure is also caused by a redistribution of the load, the traffic in one lane trying to use other lanes due perhaps to a driver stopping on a through traffic lane to load and light his pipe or calm a child, to such stoppage caused by a flat tire or mechanical trouble, or to any one of several other incidents. Where a shoulder free of moving traffic is available, the stoppage is voluntary, and the driver rolls onto the shoulder, serious interference with the traffic stream may be avoided but where a vehicle stops on a through traffic lane for any reason whatsoever when the roadway is operating at or near possible capacity drivers naturally desire to use other lanes, as shown in Figure 1. This redistributes the traffic load and causes failure or stoppage in all lanes.

The reasons for such failure or complete stoppage are best illustrated in the Highway Capacity Manual.(1) The discussion which follows is a summary of portions of Part III - Fundamentals of Highway Capacity. The charts which follow are liberal adaptations of Figures 3 and 7 of the manual and are used herein not as accurate representations of observed values but to illustrate the discussion. As a matter of fact the Committee on Highway Capacity of the Highway Research Board has been reactivated under the chairmanship of Mr. O. K. Normann and the publication of new, recently observed values may be expected soon.

Figure 2 shows average speed in relation to hourly traffic volume on the one-way roadway of a four-lane divided highway. The upper solid line represents the average speed when the highway is free flowing and there is little or no interference. The lower dashed line represents the average speed below which the hourly volume cannot be accommodated. For example, when the traffic is running at 2,000 vehicles per hour the average speed when the highway is free flowing is about 40 miles per hour. If interference of one sort or another develops, speed drops but 2,000 vehicles per hour can still be accommodated unless the interference is so severe that speed drops below 10 miles per hour, in which case cars will begin to back up. When the roadway is operating at the commonly used design value of 3,000 vehicles per hour (1,500 vehicles per hour per lane) the leeway to allow for some interference is not as great. Vehicles will travel at about 36 miles per hour when free to move and will start backing up when there is cause to reduce speed below about 18 miles per hour. When volume approaches possible capacity, or about 3,800 vehicles per hour, there is no leeway at all. Anything that will force vehicles to drop below about 30 miles per hour starts backing up the traffic. If the cause is one which still further drops the speed such as the situation in Figure 1, or an increase in volume say at the entrance from a ramp, the situation becomes steadily worse and complete failure results. The lines of stopped vehicles back up at a rapid rate as the high approach volume reaches the end of the line. Unlike ordinary streets or expressways at grade there are few points of relief, the line may become miles long and it is not unusual to take hours to unravel such snarls.

The adverse situations described are compounded due to the capacity of the roadway being reduced as the speed drops. This is illustrated in Figure 3 which represents the maximum capacity based on observing spacing of

vehicles at various speeds. When, as in the previous example, the two-lane roadway is operating near possible capacity at 3,800 vehicles per hour and say a ramp entrance pours say 400 vehicles per hour into the traffic stream, the difference between possible capacity and volume is no longer the difference between 3,800 and 4,200 but the drop in speed to say 20 miles per hour caused thereby reduces maximum capacity to about 3,400 vehicles per hour. The difference between capacity and volume is thus doubled to 800 vehicles per hour, further reducing speed, further reducing maximum capacity, further increasing the difference between capacity and volume, and so on and on until all vehicles are forced to stop and capacity is zero.

This is the situation and sequence of events which the writer believes can be corrected by a change in operation.

Obvious Remedies

This paper is not concerned with the several obvious solutions for preventing failure of expressways; full control of access which minimizes interference from the roadsides; shoulders invitingly accessible so that drivers are encouraged to stop thereon instead of on the through traffic lanes; high standard design which with access control minimizes accidents; costly policing and emergency hauling equipment prevalent in tunnels so that the effect of a vehicle stop is short lived. We are here concerned with the failure resulting from too much traffic resulting in above critical density as previously described.

One obvious solution is adequacy in the number of lanes. This leads to design of doubtful practicability in design, construction and operation but even if these problems are solved the effect of concentrating such large volumes on ramps leading to particular streets of a city is open to serious question. Its effect on the city plan and circulation may be detrimental to say the least. Furthermore it is doubtful that expressways with more than the heretofore customary 4, 6 or 8 lanes can be economically justified; even where some of the lanes are operated with reverse flow as between morning and evening peak hours.

It can easily be shown that to meet probable traffic requirements a radial expressway leading to the central area of a city should be designed with two lanes in each direction on the outskirts of the suburbs and increase steadily until 6, 7 or even 8 lanes in each direction are needed near the central area of the city. To keep the number of lanes within reason and avoid 12, 14 and 16 lane divided or multiple roadway highways, several lanes may be designed for reverse flow where it fits traffic needs and mass transit may be called upon to reduce the private transportation volume. Nevertheless a cumbersome highway with extremely serious problems of interchange results. But even if practicable solutions are possible, can such highways be economically justified? The writer thinks not, but one can never tell for sure unless an analysis is made equating the annual worth of the cost and maintenance of the additional facilities needed for the extra lanes against the annual benefit to the road users who would use the extra lanes. The writer's belief that such an equation would not show justification for the extra lanes is based on the inevitable conclusion that such lanes are needed only a small percentage of the time and are bound to accommodate a small percentage of the daily traffic. Lane for lane, an extra lane carries but a small percentage of the daily traffic carried

by a lane of say a 4 or 6 lane divided highway.

It seems far more sensible to keep the small slice of peak traffic volume off the expressway or at least delay it until the acute rush is over, particularly if it results in avoiding the expressway breakdowns now being experienced. Furthermore we have to live with expressways now in operation which may increase from 4-lane divided highways on the outskirts to 6-lane, or in rare cases 8-lane, divided highways near the city centers. The Deegan Expressway, recently completed in New York City, is six lanes divided throughout its length. The Hollywood and Santa Anna Freeways in Los Angeles have six lanes in the suburbs and eight lanes through the heart of the city. The Congress Street Expressway in Chicago has six and eight lanes. The Gulf Freeway in Houston is six lanes throughout. Not one expressway now in operation has the variation in the number of traffic lanes in keeping with the traffic demand pattern during peak hours. To keep them from breaking down is the goal of the suggested procedure which follows.

Procedure for Solution

The procedure suggested for preventing breakdowns of urban expressways because of overload is to study the traffic pattern for each and control the numbers of vehicles entering at each ramp so that no section of the expressway will operate close to possible capacity.

An urban expressway operates with a repetitive pattern. The five week-day morning peaks are much the same, with some variation on Monday morning, and the five week-day evening peaks also are much the same, with some variation Friday evening. Well established equipment and procedures are available for measuring the volumes correlated with the time of day entering each one-way roadway from each ramp and for measuring volumes, also correlated with the time of day, for numerous locations on the through roadway, at least ahead and beyond each entrance and each exit ramp. Average spot speed of traffic should be measured at numerous locations and average running speeds computed for each section between ramps. It is suggested that these data be gathered for appreciable mileage and include the expressway well beyond the areas of distress. It may be necessary to include the entire length of an expressway between points well beyond the suburbs on both sides of a city or between a point well beyond the suburbs on one side of a city to a point in the central area where good and rapid dispersion of traffic is assured. With several trials peak hours will surely be found when the expressway does not break down but just slows down for it is well known that even on an extremely inadequate capacity expressway, days of breakdown are followed by days of relative freedom of movement as some drivers caught in the jam choose other paths.

It is suggested that the data then be plotted on straight line diagrams of the expressway, hourly volume and average running speed in juxtaposition. It might be necessary to plot such line diagrams for the condition each half hour or each ten minutes or each five minutes. Also in juxtaposition should be plotted a line representing a chosen hourly volume which is somewhat below possible capacity so that there is some factor of safety, some leeway for incidents which might slow traffic but not below the speed which will start the chain reaction to failure described in the preceding part of this paper. For expressways with passenger vehicles predominating a value of 1,600

vehicles per hour per lane might be chosen or 3,200 vehicles per hour on the one-way roadway of a four lane divided highway. Referring to Figure 2, such traffic will operate with an average speed of 35 miles per hour and if interfered with can slow to an average speed of 20 miles per hour before difficulties develop.

The diagrams of hourly volume described will likely show volumes for some sections, generally those near the city center, greater than the chosen safe volume of say 1,600 vehicles per hour per lane. The solution is to remove the excess or, more correctly, prevent the volume developing above the chosen safe volume. This can be done, it is herewith submitted, by preventing complete freedom of movement on the ramp entrances approaching and in the critical section thus reducing the volumes entering from these ramps until the volume at the critical section is within the chosen safe volume. This could be done by multiplying the excess volume by the corresponding time interval for each diagram and developing a summation for the excess volume for the critical period of time, say an hour or an hour and a half or so. Relating time of day for the critical period, average running speed, and distance back to each entrance ramp leads to the time of day and period of time when volume should be reduced at each entrance ramp. By trial and error and time of day of volume reduction at each entrance ramp is determined so that the summation is about equal to the summation for the excess volume. How far back from the critical section such control should be exercised will likely be determined by judgment and trial and error. Ramps with storage space or with readily available alternate streets will be favored over others for such treatment.

It will take courage on the part of an administrator to control entrance ramp traffic particularly some distance from the critical section. At such locations the expressway is running freely and to be delayed before entering will be difficult for a driver to accept. Educational preparation and warnings will be necessary. It will be particularly important to acquaint drivers with the benefits of such operation in being able to roll along without stoppage once on the expressway. The price paid will be a short delay at the entrance ramp. It is not expected that long delays will be necessary. If, for example, the volume at a ramp entrance must be cut in half for say 30 minutes it probably will be done by closing and opening the entrance every other minute or, more likely, one minute open and a longer period closed.

Closure

The suggested procedure is untried. It should be tried. The investment in urban expressways is too great to continue allowing them to break down repeatedly without trying to change the method of operation so that traffic will keep moving. The writer believes the suggested procedure will work if intelligently applied. When the data are collected and plotted and a tentative pattern of operation determined the public should be well prepared and traffic officers, possibly with walkie-talkies, used profusely. The time it will take to work out the "bugs" is problematical. Time and great effort are necessary but the rewards will justify them.

With regard to urban expressways we are now in a similar situation we were in in the 1920's with regard to streets. Street congestion was becoming intolerable. Every driver felt he had the freedom of the streets. He

could drive anywhere and park in front of his destination. Patiently, remedies were tried and applied; stop signs, traffic lights, one-way streets, widening, curb returns, channelization, spot improvements, speed control, striping, progressive signals and what-have-you. Today, despite triple the number of vehicles, congestion is less and travel on streets is more orderly and safer per unit of travel than in the 1920's.

At the present time every driver feels he has a right to enter an urban expressway at any time on any ramp. Some control for more orderly expressway travel and maintenance of capacity is inevitable.

REFERENCE

1. Highway Capacity Manual - Committee on Highway Capacity, Department of Traffic and Operations, Highway Research Board - U. S. Government Printing Office, Washington 25, D. C.

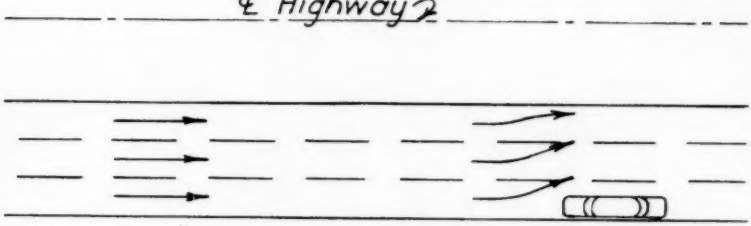

Figure 1
Operation caused by a stopped vehicle when all lanes are full

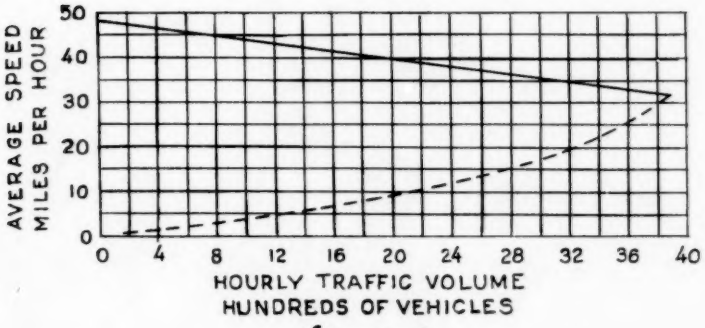

Figure 2
Speed vs Volume on a two-lane roadway of a four-lane divided highway

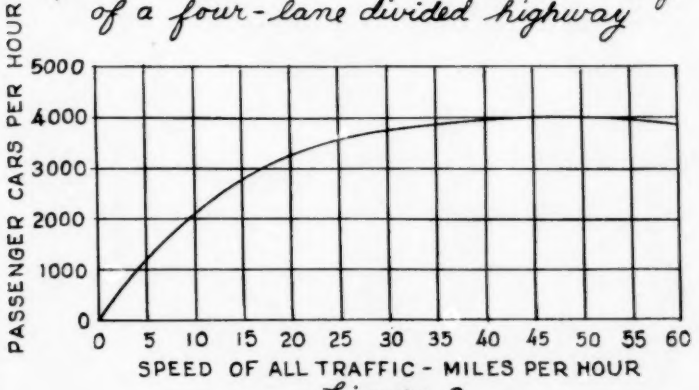

Figure 3
Maximum Capacity of a two-lane roadway of a four-lane divided highway, based on spacing of pairs of vehicles travelling at the same rate of speed

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Note: Paper 1378 is part of the copyrighted Journal of the Highway Division of the American Society of Civil Engineers, Vol. 83, HW 4, September, 1957.

Discussion of
"THE HIGHWAY SPIRAL AS A CENTERLINE FOR STRUCTURES"

by Paul Hartman
(Proc. Paper 1090)

CORRECTIONS TO THE DISCUSSION BY ANGEL PICCIO VILLASOR, JR. IN PROC. PAPER 1258.—On page 1258-10, in the line immediately preceding Eq. 2A, the word "Substituting" should be changed to "Substitution." On page 1258-11 in the first line, the dash following the letter "L" should be changed to an equality sign.

Paper 1380 September, 1957 HW 4

Journal of the
HIGHWAY DIVISION
Proceedings of the American Society of Civil Engineers

THE CONSULTING ENGINEER'S ROLE

Elmer B. Isaak[1]
(Proc. Paper 1380)

SYNOPSIS

Engineering the enlarged Federal Aid highway program is a task which will require all available talent. State highway departments will administer the work, but must supplement their own technical forces with consultants.

Consulting engineers must assume a real responsibility, constantly endeavoring to find the best solutions and using their ingenuity to advance the standards of highway building.

This century has seen automobiles supplant the carriage, movies supplant the magic lantern, and television supplant parlor conversation. Airplanes, radio, atomic developments and a thousand other wondrous things are the physical evidences of change in the most rapidly changing period the world has ever seen.

Against this background our vehicular routes have progressed from a loosely knit conglomeration of wagon roads to a nationwide system of paved highways, of which some are modern and others are far from adequate. Thirty-five years ago the effort was simply to provide connections between populated areas over which motor vehicles could pass. As automobiles improved and could achieve greater speeds and longer distances, the quality of the highway effort was stepped up to provide not only connections, but arteries permitting rapid travel.

In more recent years, entirely new and overwhelming problems have been superimposed on the old ones of how to get from one place to another and how to get there fast. These new problems are brought about primarily by one factor—the factor of volume. No longer are we dealing merely with the means for motor vehicles to travel from one place to the other, nor are we faced simply with the increasing speed and range characteristics of individual

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Paper 1380 September, 1957 HW 4

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vehicles. Now we must cope with quantities of motor vehicles—quantities in ever increasing numbers that are growing far faster than the population—faster in fact than anyone reasonably had a right to expect 15 years ago.

This new problem of traffic volume has given rise to a whole series of improvements designed to maintain and increase the free movement of motor vehicles by providing sufficient space for the numbers of vehicles desiring to move in any given direction and by eliminating interference with this movement by other vehicles traveling in opposing or intersecting directions. At the same time the factor of volume has made necessary an increased awareness of the need for built-in highway safety features if traffic movement is to be maintained.

Thus we have seen the rise of grade eliminated roadways, controlled access, center malls and then wider center malls, accelerating and decelerating lanes and finally the most modern concept of building two separate roadways for opposing lanes of traffic wherever possible.

The entire modern highway development has taken place within a span of two generations. The organization of State highway departments occurred principally in the years immediately following World War I. This movement received its biggest impetus from the original Federal Highway Act of 1916, which provided for the first participation on the part of the Government in highway developments. Since that time a Federal Aid system of some 235,000 miles of primary highways has been constructed and in addition a secondary system of over 500,000 miles has been created. The total mileage of roads and streets throughout the United States exceeds 3,300,000, most of which has either been constructed or improved in the last 40 years.

Looking back over this accomplishment, the infant highway departments of 1920 and 1925 faced Herculean tasks. There was an urgency and a desperate need to create the links that would keep our transportation and commerce flowing in an age which was already clearly destined to be carried on rubber tires. As in any urgent program the need for speed inevitably resulted in efforts toward standardization and establishment of a set of patterns which would bear repetition and overcome the necessity for treating each project as an individual original conception. The Highway Departments therefore became geared to the production of the familiar thousands of miles of rural roads connecting our cities and towns which are commonplace throughout the United States today. This program was carried through with remarkable results in the later 1920's and continued with certain financial handicaps through the 1930's.

By the middle of the '30's, however, the new problem of traffic density was beginning to rear its head in some urban areas. The State Highway Departments and the City Street Departments were still struggling with creating their basic rural and urban systems. They were not prepared to take on a brand new and specialized problem involving new concepts and a great deal of original thinking.

At this stage, developing at first in only a few of the larger metropolitan areas, the problem of what to do about traffic congestion was a special field attracting the attention of a relatively small number of those professionally concerned with highway building. Many of the early parkways and express arteries were created by special commissions or other organizations outside the regular highway departments. Since they did not have large, established engineering forces, it was natural that consultants should become involved in this work. In a number of pioneering projects consultants became

the guiding force in developing the concepts and standards for the new grade-eliminated, controlled access type of highway.

In the rise of the toll bridge and the toll road before and after World War II, the consulting engineer played an even more important part. For here it was necessary not only to design the facility but to prove its economic feasibility. Feasibility studies became the special province of the consulting engineer, and many hundreds of millions of dollars worth of revenue bonds were marketed on the strength of consulting engineers' reports. Furthermore, since most of the toll projects were the responsibilities of Authorities or Commissions, they relied largely on consultants to develop their plans and supervise construction. In most of the expressway toll projects, therefore, consultants played leading roles and their work contributed to a major extent in the development of concepts in use today.

With the impact of the factor of heavy traffic volume in the last ten years, the need for expressways, parkways and freeways has become general rather than specialized. As a consequence state highway departments were increasingly drawn into this field, and many of them have developed large mileages of this type of highway. The establishment of the Interstate System of express highways, with its 90 per cent Federal grant and the accompanying demise of the toll road movement, has catapulted the state highway departments firmly into the driver's seat. From this point on virtually all new express highways, as well as the primary and secondary road systems, will be the direct responsibility of the state departments.

Most of the states have already taken a firm hold on this problem and are well along in developing the various data, traffic studies and cost estimates required by the Highway Act. Routes have been selected for over three-quarters of the Interstate System. Plans are completed or under way for a substantial number of projects, but looking at the program as a whole this is the stage that will be hard to get off the ground. It is here that consulting engineers are being called in to help pick up the load.

The magnitude of the engineering work required for the enlarged highway program is difficult to comprehend. By applying a conventional 8 per cent for design and supervision to the estimated fifty billion dollar cost of the entire highway program for the next 13 or 15 years, the value of the engineering can be estimated at roughly $4,000,000,000. But this is only a number and doesn't mean much to most of us.

Let us try to picture somewhat more concretely what is entailed in connection with the engineering work for the Interstate System. The general routes of the Interstate Highways have been established by law in such a manner that they will connect all 48 states and will provide links between 209 cities of more than 50,000 population. The conversion of these lines on a map to plans which can be used for construction involves first of all the gathering of a great deal of information regarding the terrain to be traversed. Field investigations must be conducted, aerial photographs and mosaics obtained, available maps studied and the principal property improvements and topographic features considered in order to determine which of several possible locations is the best route. Once the route is adopted, more detailed topography must be obtained either by controlled aerial photogrammetry or by ground survey, and complete information compiled on utilities, properties and buildings to be taken, and all local conditions. Taking all these facts into account a definite location is determined and hearings must be held before a final decision is made. The major task of preparing

contract plans and specifications can then proceed. Since this is the heart of the design phase let us examine it a little more closely.

Considering a typical contract section of say ten miles of express highway built to Interstate Standards, we may picture the basic plan drawn to a scale of 50 ft. to the inch. On a 36 inch sheet this would permit approximately 1600 feet of highway to be shown. Including the profile and making some allowance for special features and configurations, a good average requirement for rural areas is about five sheets to the mile. A ten mile project would therefore require 50 sheets to show the basic highway plan, except for urban areas where the number might be close to 100. We then have a title sheet, index sheet and at least three sheets of typical sections. The tables showing alignment, earthwork, drainage features, etc., require about ten more sheets. We have not yet covered the bridges which, of course, vary greatly. Taking the case of the New York State Thruway, bridges averaged approximately one per mile. A relatively simple grade elimination bridge requires about eight sheets, so that in ten miles we might have about 80 bridge sheets. We should then allow for five miscellaneous sheets plus an average of say ten more for special utility plans, detours or unusual bridge situations. Considering that some 2300 miles of the Interstate System will be in urban areas, an over-all average for a ten-mile section might be about 175 sheets.

If we apply this standard to the 41,000 mile Interstate System we come up with the staggering total of just over 700,000 sheets of plans. Considering that the Interstate System is superimposed on the existing state road systems, and the load to be carried on primary and secondary roads is destined to increase rather than diminish, it is evident that the State highway departments are not going to be able to handle this load without help.

We have not even mentioned the question of property acquisition maps. In New York State it is necessary to prepare an individual map for each piece of property, and similar requirements exist elsewhere. That simple fact is sufficient indication of what is involved in the matter of property maps alone.

The final phase of the work, which is probably of equal importance to all that has been mentioned heretofore, is that of field supervision. Staking out the project, earthwork measurement, inspection, preparation of contractor's payment estimates and all the other elements that go into field supervision will keep all the field engineering forces available in the United States busy for years to come.

It is evident, therefore, that the fulfillment of the highway program is a task which will require the mobilization of all available civil engineering talent throughout the United States. The state highway departments alone cannot begin to cope with this problem with their own forces but it will be their responsibility to organize the job. They are in the natural position to select the projects, determine priorities, establish standards and administer the work. Fortunately the existence of a large group of consulting engineering organizations throughout the United States provides a ready source of talent to share this load. By contracting engineering work to consultants, the state departments can extend their own capacities for production without the necessity for building up their own forces beyond the level required to take care of their continuing work load. Since the accelerated program will be an extraordinary effort, even though sustained over several years, the situation is right for outside supplemental assistance as a means of avoiding staff increases in the permanent state organizations which may

later result in surplus civil service personnel.

It is hardly necessary to restate the classic advantages of the use of consulting engineers, such as the greater flexibility with which consultants can increase or decrease their organizations, their ability to attract needed talent by a more favorable salary scale and the fact that the public agency pays for desired services without increasing its own recurring payroll.

These points perhaps have greater validity than ever today. From the point of view of the national manpower shortage in engineering personnel, the more flexible employment arrangements in the consulting field afford the opportunity to make greater use of available talent, since the private organizations cross state lines and assign personnel as needed to fit the work load.

Beyond the basic need for additional manpower in the present program, there will also be numerous problems of a specialized technical nature. Only a few engineers are highly specialized in large suspension bridges, moveable bridges, certain types of foundations and other special problems. Where these occur it will be advantageous for all concerned to use the talents which have been developed in the leading organizations in these fields.

If the consulting engineer is to fulfill a vital role in the accelerated program a partnership relation must be developed between him and the highway department. To be of major assistance to the highway departments, the consultant should view his assignments from the managerial as well as the technical point of view. The consultant must consider it his duty to arrive at the best possible solution of a problem assigned to him in the interests of his client, the State. It is not enough that he follow the pattern established by a manual of standards because no manual can solve all problems or eliminate the need for thought. There is a real danger here that some engineering organizations may be satisfied with merely complying with mechanical standards without really coping with the problems at hand, giving due consideration to all reasonable alternatives and then arriving at the most advantageous solution. Only by playing a truly professional role can consulting engineers function as real partners of the highway departments and relieve them of some of the overwhelming load that now faces them.

There is one more aspect of the consulting engineer's activities in the highway program which should be noted. Mention has already been made of some of the changes which have occurred in the development of controlled access highways as they progressed from the original winding parkways of recreational character to the modern high-speed expressway designed to handle large volumes of traffic with a maximum of safety. Much of the thinking that went into the advances and changes over the years took place in consultants' offices. It will be a great pity if the consultants, in their new role as assistants to the highway departments, come to regard expressways as so standardized that their only function is to produce plans and specifications according to the established norms. Many problems still remain to be solved and some have not even arisen yet. There is no reason to suppose that the developments of the next 25 years will not be as startling as those of the last 25 and probably no one today can give an accurate description of what our super-highways will be like a generation from now.

In keeping pace with the changes and advances that inevitably come with the passing years, all engineers have a role to play if they will use their creative talents as well as their technical abilities. It is unthinkable that consulting engineers will merely follow the band wagon. New problems will stimulate new thinking and with consulting engineers working as partners

of the highway departments in advancing this great program, many vital ideas yet unborn will spring from their offices to the benefit of the transportation routes and the economy of our nation.

Paper 1385 September, 1957 HW 4

Journal of the
HIGHWAY DIVISION
Proceedings of the American Society of Civil Engineers

SIGNIFICANCE OF TESTS FOR HIGHWAY MATERIALS - BASIC TESTS: PROGRESS REPORT OF THE COMMITTEE ON SIGNIFICANCE OF TESTS FOR HIGHWAY MATERIALS OF THE HIGHWAY DIVISION

(Proc. Paper 1385)

FOREWORD

The Committee on Significance of Tests for Highway Materials of the Highway Division, ASCE has undertaken the preparation of the following text with an appreciation of the problems involved in the presentation of such a compilation. However, the members of the committee strongly feel that while there is bound to be some slight misunderstanding of our purpose and perhaps some misuse of the material, there is a compelling need for the better understanding of the significance of the values resulting from tests for highway materials among highway engineers.

Highway engineering and the use of engineers on highway projects have changed radically in the last decade. Seldom before in the history of the profession have young engineers had the opportunity to assume responsibility as early in their professional careers. The years of apprenticeship have been reduced to an absolute minimum due to the pressure of work and a shortage of qualified engineers. In addition, engineers ordinarily devoted to other phases of Civil Engineering are now called upon to help meet the engineering manpower shortage created by the increased and increasing public demand for improved highway transportation.

The result of such a situation is uncertainty brought about by inexperience. Inexperience by itself is not critical but inexperience coupled with responsibility is the problem. One solution is to resort to unnecessary and usually expensive overdesign. Another is to make use of specialists and centralized control. This last solution is also inefficient in the use of time and often the lack of personal knowledge of field conditions of materials leads to wrong inferences. While this system is workable its determinations must be checked on the job. In order to be effective, field checks require some appreciation of the significance of test results.

The Committee came to the conclusion that some means must be found to bridge the gap between the superficial knowledge of the somewhat inexperienced engineer and the relatively complete knowledge of the materials engineer. It is freely admitted that all the material in the following pages is available somewhere in the literature dealing with highway materials. But,

Note: Discussion open until February 1, 1958. Paper 1385 is part of the copyrighted Journal of the Highway Division of the American Society of Civil Engineers, Vol. 83, No. HW 4, September, 1957.

few engineers have available either the library or the time to devote to such a search. The Committee therefore has gathered and interpreted sufficient data for an appreciation of the significance of some tests for highway materials.

The following pages contain discussions of what are considered by the Committee to be the basic tests in the areas of Soils, Bituminous materials and Concrete and Concrete Aggregates. These fundamental tests in these three areas were considered by the committee to be the minimum acceptable coverage. It is hoped that without too great delay similar treatment may be accomplished in the other areas of highway materials. Eventually the committee plans to cover the less common but accepted tests and finally the tests of a controversial nature.

We of the committee will be the first to explain that any one test or any one test value by itself is not conclusive. In fact one test or value if not brought into proper perspective with the necessary supplementary or complimentary tests and/or values may be definitely misleading. We have attempted to bring this point out along with our discussions of significance of the tests and the test values.

We would also like to emphasize the fact that tests and testing of Highway materials are going through a continual evolution process. Test measurements are only approximations of exceedingly complex combination. Therefore in the Highway materials field no test or test procedure should be considered to be in its final form.

SOILS

Mechanical Analysis

(Sieve and Hydrometer Analyses)

ASTM Test Designation - D 422-39
AASHO Test Designation - T 88-49

Significance of Test

The mechanical analysis of a soil is the determination of the percent of individual grain sizes present in the sample.

The results of the tests are of most value when used for classification purposes. Further use of the gradation should be discouraged unless verification by studies of performance or experience permit empirical formulae. Only rough approximations of strength or resistance properties should be attempted. Quite often it will be found that the larger the grain size, the better are the engineering properties. Also, it is a known fact that detrimental capillarity and frost damage are not a problem with the coarse (sandy) material whereas it can be very dangerous with the fine-grained silts and clays. Some empirical relationships have been developed such as the criterion commonly used for determining the susceptibility of soil to pumping under rigid pavements. Highway specifications for sub-base and base materials also use the grain size analysis for quality measurement.

For soil stabilization, use is frequently made of grain size analyses for

mix design and control. One criterion for bituminous stabilization is a requirement for a minimum percent of sand and gravel size. The percent of cement to be used in soil-cement mixtures can be estimated on the basis of the grain size. For mechanical stabilization or aggregate bases (well graded granular material with or without a chemical admixture) the results of the gradation tests are used to determine the size and percent of aggregates or fines that are needed for a dense, impermeable material.

On occasion, the degree of permeability (measure of the amount of water that will flow through a material) is estimated on the basis of grain size. Here again, certain generalities are possible but accurate estimates are not. The larger-grained soils will more readily permit the flow of water than finer-grained ones; i.e., sands are more permeable than silts, and silts are more permeable than clays. An example of the variation from this generality is a well-graded, granular material which can be sufficiently impermeable to serve as a core for an earth dam.

Synopsis of Test Methods

The mechanical analysis consists of two parts; one, the determination of the amount of coarse material by the use of sieves or screens; and two, the analysis for the fine-grained fraction commonly employing an hydrometer analysis.

The sieve analysis is a simple test consisting of sieving a measured quantity of material through successively smaller sieves. The weight retained on each sieve is expressed as a percentage of the total sample.

The hydrometer analysis is conducted on a sample of the material that passes a No. 200 sieve. The test is based on the principle that the soil can be dispersed uniformly through a liquid. The specific gravity of the soil-liquid mixture is then measured at various time intervals. Stoke's Law is used to compute the rate of settling of the various sizes; i.e., the larger grains settle more rapidly than the smaller grains. The computations include corrections for temperature, viscosity of the liquid and the specific gravity of the soil particles. The results are first expressed as a percent of the sample used in the hydrometer analysis, and then converted to percentages of the total soil sample if there is a coarse grained fraction.

Typical Test Results

The results of the mechanical analysis can be presented in either of two forms. One is a table in which there is listed the percentage of the total sample that will pass a given sieve size or is smaller than a specified grain diameter. The second form is a plot of the sieve number or grain-size vs. the percentage passing the given sieve (smaller than the given diameter). For this latter form, grain size is normally plotted on a logarithmic plot due to the wide range in values, while the percentage finer is plotted on an arithmetic scale.

Nomenclature has been established for materials within certain grain-size limits. In decreasing order of size these groups are as follows:

gravel - coarser than 2.0 mm. (No. 10 sieve)
coarse sand, 2.0 - 0.6 mm (No. 10 - No. 30)
medium sand, 0.6 - 0.2 mm (No. 30 - No. 80)
fine sand, 0.2 mm - 0.05 mm (No. 80 - No. 270)

silt, .05 - .005 mm
clay, finer than 0.005 mm
colloids, finer than 0.001 mm

Soils designated as sandy will contain more than 50% sand or gravel size. Silty soils will contain from 40% to as great as 100% silt size. Clays will contain as low as 30% or as high as 100% clay and colloids. Gravelly soils will normally contain at least 15% gravel-size material.

Influences of the Methods of Test

For the sieve analysis, care must be taken to remove clay and silt that may be adhering to the sand and gravel. In preparing the sample for testing, one must avoid fracturing some types of soft gravel and stone particles. For the very fine sands (#100 or #200 sieves) it will be desirable to wash the sample through the sieves.

The hydrometer analysis is particularly susceptible to poor results due to technique. The following are major sources of error:

1. Improper deflocculation (failure to separate the material into individual grains).
2. Improper mixing of soil and liquid.
3. Careless placement and removal of the hydrometer.

Consistency Tests and Indices

(Atterberg Limits)

Liquid Limit	-	ASTM Designation - D 423-39 AASHO Designation - T 89-49
Plastic Limit	-	ASTM Designation - D 424-39 AASHO Designation - T 90-49
Shrinkage Limit	-	ASTM Designation - D 427-39 AASHO Designation - T 92-42
Plasticity Index (PI)	-	ASTM Designation - D 424-39 AASHO Designation - T 91-49

Significance of Test

The consistency tests or the Atterberg Limits consist of the Liquid limit, the plastic limit, and the shrinkage limit. A value frequently used in conjunction with these limits is the plasticity index. The engineering properties of soil vary with the amount of water present, and results of the three consistency tests, expressed as moisture contents, are arbitrarily used to differentiate between the various states of the material. The liquid limit is the moisture content at which the soil changes from the liquid to the plastic state. The plastic limit is the border between the plastic and semi-solid, and the shrinkage limit delineates the semi-solid from the solid state. The plasticity index is the arithmetic difference between the liquid and plastic limits; i.e., it is the range of moisture content over which a material is in the plastic state.

The most common application of the test results to highway problems is in soil classification with those soils with comparable limits and indices classed

together. Generally, soils with high liquid limits are clays with poor engineering properties. A low plasticity index indicates a granular soil with little or no cohesion* and plasticity. Both the liquid limit and the plasticity index are used to some degree as a quality measuring device for pavement materials, in order to exclude those granular materials with too many fine-grained particles that have cohesive plastic qualities.

During recent years, many laboratories have abandoned the use of the shrinkage limit. In the highway field, classification is most commonly made on the basis of the Highway Research Board system which requires the gradation, the liquid and plastic limits, and the plasticity index.

Synopsis of Test Methods

The liquid limit test consists of molding a soil pat in a brass cup, cutting a groove in the pat with a special cutting tool and dropping the cup onto a solid base from a constant height. The liquid limit is that moisture content at which the groove closes for a length of 1/2" under 25 impacts.

The plastic limit test consists of rolling a soil sample into a thin thread. The soil thread is made by rolling a wet sample on a plate with the hand. This procedure is repeated until the sample crumbles when the diameter of the thread is equal to 1/8". The moisture content of the soil in this latter condition is the plastic limit of the soil.

The shrinkage limit is conducted by saturating a soil sample, placing the material in a small dish of known volume, and weighing. The specimen is then placed in an oven and dried to a constant weight. During the drying period, the sample shrinks and loses volume at a rate more or less proportionate to the volume of water evaporated until the shrinking stops abruptly. The shrinkage limit is the moisture content of the saturated sample at the time the shrinkage ceases.

Typical Test Results

The liquid limit varies widely and values as high as 80 to 100 are not uncommon with values of 40 to 60 more typical for clay soils. For silty soils, values of 25 to 50 can be expected. The liquid limit test will not produce a result for a sandy soil, and the results are reported as "non-plastic."

The plastic limit of silts and clays will not vary too widely and will range from 5 to 30. Normally, the silty soils will have the lower plastic limit. Since a pure sand is non-plastic, the thin thread cannot be rolled and the material is termed "non-plastic." For the shrinkage limit, clays may range in values from 6 to 14, with silty materials most frequently showing values between 15 and 30. Pure sand will show no decrease in volume during the drying period.

The plasticity index can be as high as 70 to 80 for the very plastic clays. Commonly, clays will have P.I.'s between 20 and 40. The silty materials normally range in P.I. between 10 and 20. For quality evaluations, bases, sub-bases, and subgrades are sometimes restricted to those materials with a liquid limit of 25 or less and a maximum P-I. of 6; i.e., a predominantly granular material.

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* Cohesion can be pictured as the inherent property which makes it difficult to pulverize a dry soil into individual soil grains. The amount of cohesion decreases with an increase in moisture content.

Influences of the Methods of Tests

For the liquid limit the most common sources of error include (1) inaccurate height of drop of the cup, (2) a worn cup due to scratching with the grooving tool, (3) too thick a soil pat, (4) the rate of dropping the cup and (5) the human element in deciding when the groove has closed 1/2".

In many laboratories where production is a major concern, the test is conducted using only one moisture content, taken when the material is considered to be at the liquid limit. In the standard method of test, at least three moisture contents are determined, one below the liquid limit, one at or near the liquid limit and the third higher than the liquid limit. The results are plotted by placing the moisture content on an arithmetic plot with the number of blows on a semi-log basis. This permits a more exact establishment of the liquid limit.

Moisture - Density Test

(Proctor Test)

ASTM Test Designation - D 698 - 42T
AASHO Test Designation - T 99 - 49

Significance of Test

The moisture-density test is designed specifically to aid in the field compaction of soils so as to develop the best engineering properties of the material. It is assumed that the strength or shearing resistance of the soil increases with higher densities. Thus, the test is designed to get the best results from the soil available.

The "standard" moisture-density test as conducted in the laboratory uses a constant laboratory compactive effort, and it is assumed that it is similar in magnitude to the weight, impact and action of the average construction equipment. As might be anticipated, a greater compactive effort will bring an increase in density, and such a procedure was followed in developing the so-called "modified" moisture-density test. Presumably, heavier construction equipment would be required to obtain the "modified" density than would be needed to get "standard" density.

Another important factor is that the presence of a certain amount of water is needed in order to get the densities desired. For simplicity, the water can be assumed to act as a lubricant. However, too much water tends to force the particles apart and the higher densities cannot be obtained. Therefore, the laboratory test not only defines the density that should be obtained by the construction equipment, it also delineates how much water should be used during the compaction.

Given a density (termed maximum density) and the proper moisture content (termed optimum moisture content) the construction forces can compact the soil into the best condition practicable. As a check, field forces employ a density test to determine the density obtained by the construction equipment. If the results are lower than the value permitted by the specifications, the material should be recompacted.

Synopsis of Test Method

The total sample is permitted to dry in air until a damp condition is reached. From this, a sample of the material passing the No. 4 sieve is selected. The soil is then compacted in three layers into a metal, cylindrical mold of known volume. A metal rammer is dropped from a height of 12 inches onto the soil in the mold. A total of 25 blows per layer is used. The weight of the soil in the mold is determined, and with the volume of the mold known, the density is computed by dividing the weight by the volume. A moisture content determination is made on the sample in the mold. The soil is then removed from the mold, pulverized, an increment of water mixed into the sample, and the compaction procedure repeated. The test continues until the weight of the compacted sample in the mold is equal to or less than that obtained in the preceding step.

Typical Test Results

The computations include a plot of the moisture content versus the density obtained with that moisture content. Calculations are then made of the density of the soil grains only; i.e., excluding the weight of the water. This density is also plotted versus the moisture content and is termed the "dry density" curve. The resulting plots are curved lines showing higher densities with increased moisture content up to some peak, and then lower densities with increased moisture content. The density at the peak of the dry-density curve is called the "Maximum Density" and the moisture content at that point is termed the "Optimum Moisture Content."

The following is a list of the range of values that might be anticipated for the standard moisture-density test:

Clays - Maximum density	90-105 lbs. per cu. ft.
Optimum moisture content	20 to 30%
Silty-clays - Maximum density	100-115 lbs. per cu. ft.
Optimum moisture content	15 to 25%
Sandy-clays - Maximum density	110-135 lbs. per cu. ft.
Optimum moisture content	8 to 15%

For the modified procedure using an increased compactive effort, maximum densities of 10 to 20 pounds per cubic foot larger can be anticipated with optimum moisture contents of 3 to 10% lower.

For sandy or gravelly soils with no fines, there is no significant change in density with the use of water unless inundation methods are used.

Many compaction specifications require that a percent of the maximum density be achieved. This percent varies from 90 to 95% for the more granular materials and 95 to 100% for the fine-grained silts and clays. The percent of maximum density is the ratio of the density obtained to the maximum density expressed as a percentage.

Influences of the Methods of Test

The test is not particularly susceptible to dangers from poor laboratory technique. The degree of accuracy of the field density test, and the differences in the soils in the field and that used in the laboratory preclude a highly accurate determination.

However, certain laboratory precautions must be taken. In the mixing of

the water into the soil, as thorough a mix as possible is necessary. In taking the moisture sample, care should be taken to obtain a representative sample. For very granular soils with a large portion retained on the No. 4 sieve, an adjustment is necessary to compensate for the removal of this material prior to testing.

There is considerable argument as to the adequacy of the laboratory compaction as compared to that obtained by construction equipment. The question arises as to the size, weight and drop of the rammer, as well as the manner in which the soil is compacted. However, as long as the specifications require the standard test, the argument is not a factor to the construction forces in their routine operations.

The field density test to determine the density obtained by the construction equipment has been successfully conducted using any one of three different devices for measuring the volume of the hole from which a sample has been removed. The three techniques include calibrated sand, a viscous liquid, and water encased in a light rubber membrane. A fourth method involving the removal of a sample by driving a thin-walled sampler into the soil is satisfactory for fine-grained silts and clays but not for material containing a significant amount of gravel or rock fragments.

Unconfined Compressive Strength

ASTM - Suggested Procedure in
"Procedures for Testing Soils"
July, 1950

Significance of Test

The unconfined compressive strength test of soil is most frequently classed with shear tests for the procedure can be immediately recognized as a tri-axial shear test with zero lateral pressure. Therefore, for this phase of the test, the reader is referred to "Shear Tests" for a more complete discussion. The following deals with the test as employed for purposes other than shearing resistance for stability analyses.

For soil stabilization, the unconfined compressive strength is used in much the same manner as for concrete. In such instances, the compressive strength is used to evaluate the adequacy of the mixture, in conjunction with weathering tests, gradation and percent of admixture.

The actual value of the compressive strength in pounds per square inch is not used for design purposes, nor is the modulus of elasticity that is available for the load-deflection data. Rather, the data are principally significant for control purposes.

Synopsis of Test Method

Except for the size of the sample, the rate of loading and the curing of the specimen the procedure can be quite similar to the compressive strength tests for molded concrete cylinders (ASTM C 39 - 49 or AASHO Test T 22-49). The exceptions noted are related to the soil characteristics which usually lead to smaller soil cylinders, a slower rate of loading, and longer curing periods.

Typical Test Results

The load versus deflection curve can be plotted but the ultimate compressive strength is more frequently used in soil stabilization. For mixtures that produce a reasonably rigid material, the load deflection curve may be a straight line over a relatively long range, indicating a fairly elastic material.

The ultimate compressive strength of soils and soil mixtures varies over a wide range. For soil-cement, clay soils will fall in the range of 200 to 600 p.s.i., while sandy-clay mixtures may range from 500 to 1800 p.s.i.

Influences of Method of Tests

As used in the control of mixtures, the test is not particularly susceptible to poor results due to inadequate technique. The rate of loading should be watched critically, as should the curing time for the specimen. The problem with curing is not solely related to the proper development of strength, for the soaking period is dependent primarily upon obtaining a saturated sample. Generally, a soil mixture has the least strength when in a saturated condition.

Shear Tests

ASTM - Suggested Procedure in
"Procedures for Testing Soils"
July, 1950

Significance of Tests

Shear tests of soils are used in highway engineering to determine experimentally the shear characteristics of a soil. From this data, an estimate is made of the resistance of the same type of soil to shearing within, beneath, or adjacent to an engineering structure. Normally, test values are applied to a form of stability equation to determine the probability of a soil shearing under the loads and conditions imposed.

The shearing resistance offered by a soil is an important factor in many highway problems. Pavements, embankments, and many structures rest directly on soil, while most embankments are composed of soil materials. The shearing of the soil can result in complete pavement disintegration, collapse of a structure, or the loss of an embankment through sliding. The prediction of the unit shearing resistance is the objective of the laboratory shear tests. The application of the results is a problem involving soil mechanics.

The principal types of shear tests are the direct shear and the tri-axial shear. The primary difference between the two lies in the equipment and technique used.

Synopsis of Test Method

All laboratory shear tests require a sample that is as similar to field conditions as possible. In addition, the loads imposed in the laboratory should approximate the actual loaded conditions. This requires an "undisturbed" sample for those situations where the soil is not to be reworked or recompacted in or around the structure. Where the soil is to undergo compaction or other manipulation, the sample for laboratory testing must be prepared in

anticipatiqn of the future condition of the soil. An "undisturbed" sample is one which is carefully removed from the ground with as little disruption as possible. The field moisture contents are maintained by sealing the sample with paraffin, and, in the laboratory, the sample is carefully cut to the dimensions required by the testing equipment.

Shear tests are further sub-divided into "quick," "consolidated quick" and "slow" tests depending upon the loading conditions required. The essential difference lies in the variation in moisture content during the test. For quick tests, the sample is loaded relatively rapidly so that the moisture content does not change, while in slow tests, water is permitted to drain freely from the sample during the testing. For the consolidated quick test, the sample is preloaded and permitted to drain prior to the shearing of the sample. This variation is required in order to more closely approximate the actual conditions to which the soil is or will be subjected.

Direct Shear

The equipment for direct shear tests require a sample in the form of a disc that is 2 to 3 inches in diameter and approximately 0.5 inches thick. Also used, are 3-inch by 3-inch and 4-inch by 4-inch square soil samples of the same thickness. The sample is frequently saturated prior to testing to represent the most critical condition for the given soil structure. After placing the sample in the lower (holding) plate of the testing device the upper plate is placed in position, and a shearing load (perpendicular to the axis of the sample) is applied. Measurements are made of the load applied (in increments) and the lateral displacement. The test is conducted on a minimum of two preferably three separate soil samples. For each of the three samples, a normal or compressive load is applied in a direction parallel to the axis of the soil cylinder. This normal force is changed for each sample.

Tri-Axial Shear

The soil sample varies in size with the requirements of the testing device, but frequently consists of a 2.8-inch diameter cylinder, 6.5 inches in height. Generally the sample is saturated so as to represent the most critical condition for the given soil structure.

The tri-axial equipment consists of a lucite (plastic) cylinder several inches larger in diameter than the soil sample. The lucite is capped top and bottom with removable metal plates. On the top and bottom plates there is a carbonundum porous disc. The soil sample is placed inside a rubber membrane, which is slightly smaller than the specimen, and the compressive load applied by a piston arrangement through the top metal plate. A uniform lateral pressure on the rubber-encased sample can be obtained by the use of a gas or liquid within the lucite cylinder.

A series of three tests is run using a different lateral pressure for each of the three tests. Measurements are made of the compressive load applied and the deformation of the sample in a direction parallel to the axis of the cylinder.

Typical Test Results

The shear test results are computed and analyzed in similar fashion; i.e. without too much difference as to the type of test. Load versus displacement curves are plotted, and the critical point on the curve determined. This critical point is related to the allowable displacement, the slope of the load-displacement curve, and other factors. It is generally more difficult to

delineate the critical point than for similar curves for concrete and steel since soil is elastic over a very small range of load.

The actual shear value in pounds per square inch is not the desired result. Rather, shearing resistance of soil is generally assumed to result from "friction" and "cohesion." The frictional characteristic is grain-to-grain resistance commonly associated with the term friction as applied to the sliding or rolling resistance between two masses. Cohesion is an inherent property of soil that can be pictured as (1) a form of cementing action for well graded gravel-sand-clay mixes, and (2) an adherence between fine-grained particles for clay materials. Since frictional resistance is increased by normal or compressive loads, the shearing resistance of the soil in the field will be influenced by the loads perpendicular to the plane of shear. Therefore, laboratory shear tests determine the "angle of internal friction," commonly designed by ϕ, and cohesion, usually termed "c." These two values are then considered to be constant for the field conditions and the actual shearing resistance computed.

Typical values for friction and cohesion are as follows:

Sandy soils:	$\phi = 28^{o}$ to 45^{o}
	c = 0 to 300 p.s.i.
Clay soils:	$\phi = 0^{o}$ to 15^{o}
	c = 100 to 1000 p.s.i.

Generally, sandy soils develop their shearing resistance through friction with little or no cohesion. The opposite is true for clays as the bulk of their resistance is from cohesion. Where an unconfined compression test is used for a clay soil, and ϕ can be assumed equal to zero, the value of "c" is one-half the compressive strength.

Influence of the Methods of Tests

Since laboratory shear testing assumes that the soil sample is in the same condition as the actual soil in place, and since the shearing resistance of soil is vitally influenced by changes in particle arrangement, it is essential that the laboratory specimen be as similar to the soil in place as possible.

Furthermore, the shearing resistance of soil is quite variable depending upon conditions that exist before, during, and after loading. It is essential that the laboratory procedures approximate the loading conditions in the field.

For the direct shear test, laboratory techniques must insure that there is no contact between the upper and lower plates, and that the lateral or shearing loads are perpendicular to the axis of the specimen.

For the tri-axial shear test, the hydrostatic or water pressure in the void space between grains is a critical factor during the loading. This "pore pressure" is measured and evaluated.

Since improperly conducted shear tests can lead to very erroneous stability computations, a more experienced laboratory technician is required than for the classification tests.

Consolidation Test

ASTM - Suggested Procedure in
"Procedures for Testing Soils"
July, 1950

Significance of Test

The consolidation test is of primary use in estimating the rate of settlement and the total amount of settlement of a soil layer under an applied load. The procedure and analysis is restricted to problems involving saturated soil masses, principally clays or other soils with low permeability.

When a load is applied to a soil mass, the immediate tendency is for the soil particles to be compressed or pushed closer together. However, the mass is saturated, and the water being incompressible must initially carry part of the load. This produces an internal pressure commonly termed "pore pressure," and the water proceeds to drain from the voids between the grains. In very impermeable soils, this drainage requires an extended period of time. During this period of drainage, the soil particles are forced closer and closer together producing a volume change or settlement. The phenomenon can continue for many years in an impermeable clay, or take place almost immediately in a clean sand.

The laboratory test attempts to determine in an accelerated manner, this rate of settlement, as well as the total amount to be expected under the total load applied. These values are important for analyses of structural foundations placed on saturated soil masses, or under very large structures where a relatively thin bed of the saturated clay lies at a considerable depth beneath the foundation footing.

More recent applications have been in the analyses of highway embankment settlement and the slope stability during the construction stages. Vertical sand drains have been used to accelerate settlement by providing more available passageways for the escape of the pore water. With the shorter distances for the water to travel to get out of the clay, settlement proceeds at a more rapid rate. The pavement can then be placed on an embankment for which the bulk of the settlement is complete.

Stability is also a factor. The shearing resistance is lower during the period of high pore pressures (see Shear Tests). Thus, the consolidation test can be used in determining how rapidly the height of the embankment can be increased during construction without producing a shear failure in the saturated clay mass.

Synopsis of Test Method

Prediction of the settlement of a structure by the use of a laboratory test requires that the sample used be as nearly identical and representative of the soil mass as is possible. The discussion relative to "undisturbed" samples for a shear test is pertinent to consolidation tests (see Shear Tests).

The soil sample is cut and trimmed so as to fit into the metal ring provided for the test. The cut sample is normally a disc approximately four inches in diameter and one inch in thickness. Porous carborundum discs are placed beneath and on top of the soil specimen, and the assembled sample, discs, and ring are placed in a loading unit. A compressive load is applied, and deflection readings are taken at set time intervals. The load is not

changed for 24 hours, at which time the unit load is doubled. The procedure is followed through four to six load increments. At the conclusion of the test, approximately 3/4 of the load is removed and the sample is permitted to rebound for at least four hours. Finally, all but a slight fraction of the load is removed and an additional four hour rebound period elapses before the test is complete.

Typical Test Results

Two principal values obtained from the consolidation test are the compression index, designated by "C_c," and the coefficient of consolidation, or "c_v." These values are computed from the test data, and the results used to estimate the rate as well as the total settlement under a given load condition. The compression index is used in the analysis of total settlement and is a dimensionless factor normally ranging in value from 0.1 to 0.3 for silty-clays and from 0.2 to 1.0 for clays. Higher values tend to produce larger settlement estimates. The amount of total settlement is also related to the thickness of the layer under consolidation and the applied load. Total settlements within the range of 6 inches to 18 inches are not unusual.

The values for the coefficient of consolidation are in units of square feet per second and range from .002 to .0002 for silty clays to .0001 to .00002 for clays. The data is used to estimate the amount of settlement for a given period of time under a given load increase. The settlement for the time period is compared with the total settlement for the load and the "degree of consolidation" is the ratio of the two expressed as a percent. Thus, in the construction of a 30 foot embankment if the work continues until a height of 10 feet is reached, a time lapse of three weeks may produce a degree of consolidation of 90%. Subsequently another 10 foot height could be added, and time for settlement allowed. Construction procedures of this type permit an underlying, saturated soil mass to eliminate pore water, develop shearing resistance, and thus eliminate foundation or shear failures.

Influences of the Methods of Test

The value of the test is largely dependent upon the ability to duplicate in the laboratory the field conditions of the soil, the loads imposed, and the drainage characteristics. An "undisturbed sample" is a major factor, as is a proper interpretation of the rate of loading. With the test procedure itself, the friction between the soil and the metal ring and the size of the specimen are critical factors.

In general, the laboratory procedure and the engineering associated with the test arrangement and the analysis will require an experienced laboratory technician. Working with the technician, there must be a competent engineer who is thoroughly familiar with the inaccuracies and limitations of applying the laboratory consolidation test and theory to settlement predictions.

BITUMINOUS MATERIALS

Asphalt Residue of Specified Penetration

ASTM Test Designation - D243-36
AASHO Test Designation - T45-42

Significance of Test

This test is intended to determine the amount of useful semi-solid asphaltic binder in slow curing cut-backs. If the major changes which occur in the material in service are due to evaporation and if no chemical changes occur during the test due to the heating, the test result is valid. There is however, some evidence that the major changes in the slow curing materials in service are not due to evaporation. Furthermore it has been demonstrated that the long test heating periods at high temperatures will transform certain heavy volatiles into asphalt-like bodies. This is particularly true for materials requiring a long time to come down to the specified (usually 100) penetration, so that several authorities have suggested specifying a maximum time for reduction. For the above reasons the test results are of doubtful value. A vacuum-distillation test has been substituted by several organizations. The ASTM has a tentative standard vacuum-distillation procedure (D1189-52T) for this test.

Synopsis of Test Method

In this test a 100 gm sample of slow curing cutback (road oil) in a 6 oz. metal (gill) can is heated in a cast iron air bath at a temperature between 480° and 500°F. When the operator considers that sufficient evaporation has occurred the material is cooled and the 77°F penetration determined. The operation continues until the residue reaches the specified (usually 100) penetration (± 15). The percentage by weight of residue is then determined.

Typical Test Results

The residue of specified penetration test is used in many specifications for slow curing cut-backs (road oils). The specifications for grade SC-0 require 40% or more of 100 penetration residue and for grade SC-5 80% or more of 100 penetration residue.

Influence of Method of Test

The test requires careful attention to temperature and to stirring of the sample from time to time to avoid local overheating. Skill is required in judging when to stop heating in order to have the material at the proper penetration.

Float Test

ASTM Test Designation - D139-49
AASHO Test Designation - T50-49

Significance of Test

The float test is useful for controlling the consistency of the semi-solid tars and soft asphaltic residues. It has no direct relation to the quality of the materials. Melting points and temperature susceptibility are reflected in float test results to some degree. It has also been used to define the cured out* point for all types of cut-back asphalts. Experience has shown that the materials can be considered cured out when the residue has about 120 sec. float test at 50°C.

Synopsis of Test Method

The test is made by molding a small plug of the material to be tested in a standard brass collar, cooling to 5°C (41°F), mounting the collar in a standard aluminum float and floating the assembly in a hot water bath maintained at a specified temperature (usually 32°C or 50°C). The time in seconds between placing the float assembly in the hot water bath and the instant when the water breaks through the plug is the float time.

Typical Test Results

Specification values for road tars vary from a low of 50-80 seconds at 32°C for grade RT-7 to a high value of 150-220 seconds at 50°C for grade RT-12. Specification values for distillation residues of slow curing cut-backs vary from a low value of 15-100 seconds at 50°C for grade SC-0 to 75-200 seconds at 50°C for SC-5.

Influence of Method of Test

The test is sensitive to temperature and precise control is required for good results.

Flash Point Test

ASTM Test Designation - D92-52
AASHO Test Designation - T48-53 and T79-42

Significance of Test

The flash point test is purely a safety test. It indicates the maximum temperature to which the material can be safely heated. Ordinarily semi-solid asphaltic materials should not be heated to temperatures higher than 50°F. below the flash point. The cut-back asphalts, particularly the rapid-curing type, are often used at temperatures above their flash point. A definite fire hazard exists in this case and serious accidents may result.

* When the liquifying agent in the cut-back has evaporated leaving the base asphalt the cured out point has been reached.

The specifications establish a minimum flash point for asphaltic materials. For semi-solid asphalts the requirement is usually 350°F or higher. For the cut-back asphalts the usual requirements are 80°F for rapid curing, 100° to 150°F for medium curing and 150° to 275°F for slow curing.

Synopsis of Test Method

The asphaltic material is heated at a uniform rate in an open brass (or glass) cup. Periodically a small test flame is passed across just above the surface of the heated material. The temperature at which the vapors ignite with a brief flash of blue flame is the flash point.

Typical Test Results

The flash points of semi-solid asphalt cements will generally be in the range from 475° to 600°F. Rapid curing cut-backs may flash as low as 80°F. and commonly have flash points of 90°-100°F.; the medium-curing cut-backs generally flash between 125° and 210°F. while the slow curing cut-backs (road oils) generally have flash points above 230°F.

Influence of Method of Test

The flash point test is a simple test. Best results are obtained when the test is performed in a darkened room. Attention to rate of heating is important. The level of filling and elimination of movements of air over the cup are also important. If silicones have been added to asphaltic materials the surface films must be broken by stirring or a wrong flash will be obtained.

Loss on Heating Test

ASTM Test Designation - D6-39T
AASHO Test Designation - T47-42

Significance of Test

The loss on heating test is widely used in specifications for asphalt cements and is used in some specifications for slow curing cut-backs.

The test is somewhat representative of conditions of heating in field storage tanks, but is not representative of conditions during plant mixing or distributor operation because of differences in film thickness. Loss in weight is nearly always small, 0.5 per cent or less, and is of no particular significance. Rapid loss in penetration during the test is indicative of possible rapid hardening under field conditions.

The Bureau of Public Roads has made an extensive investigation of a "Thin Film Oven Test" in which the paving asphalts are heated at 325°F for 5 hours in a film about 1/8 inch thick. This test condition is more nearly representative of actual field conditions and should give more valuable information than the standard test. It has not been widely used.

Synopsis of Test Method

A 50 gm sample is placed in a 3 ounce metal (gill) can and held at 325°F for 5 hours in a revolving shelf oven. After the sample is cooled the loss in

weight during the test is determined and is expressed as a percentage of the original weight. The penetration of the loss on heating residue (in the case of asphalts) is usually determined and compared, percentage wise, with the penetration of the material before heating.

Typical Test Results

The specifications for semi-solid asphalt cements usually require that the maximum loss in weight be 1 per cent and that the penetration after heating shall be at least 60-70 per cent of the original penetration. Losses in weight seldom exceed 0.5 per cent and some materials may show slight gains. Final penetrations are nearly always within specification limits.

Influence of Method of Test

Dissimilar materials should not be tested in the same oven at the same time because the volatiles from one sample may be absorbed by a less volatile sample which will then show an actual weight gain. Careful attention to proper heating temperature and to proper time is required.

Viscosity Tests

ASTM Test Designation - D88-53 (Asphaltic materials)
AASHO Test Designation - T72-46 (Asphaltic materials)
AASHO Test Designation - T54-35 (Road tars)

Significance of Test

The viscosity tests are used to control the viscosity of liquid bituminous materials. Viscosity test results are useful in selecting materials for specific uses. Low viscosity materials are used for priming. The blade mixing of graded aggregates containing 5 to 15 percent of -200 material can be most successfully accomplished with materials having Saybolt Furol viscosities less than 300 sec. at 140°F.

Elevated temperature-viscosity relations are not specified for semi-solid asphalt cements and semi-solid tars. However, the temperature viscosity curves can be quite useful in selecting heating temperatures for various uses of the materials. It has been suggested that the optimum temperature range for distributor application is that for which the material has a Furol viscosity of 50 to 150 seconds. Plant mixing requires heating the materials to a temperature range in which the Furol viscosity is 80 to 200 seconds.

Synopsis of Test Method

The viscosity of liquid asphaltic materials is measured with the Saybolt Furol viscosity test. This test measures the flow time, in seconds, for 60 ml to pass through a standard tubular opening under a standard head and at a standard temperature. Standard temperatures of 70°, 77°, 100°, 122°, 130° 140°, 180°, and 210°F are used. The viscosity of liquid tar is measured with the Engler specific viscosity test. In this test the flow time, in seconds for 50 ml of tar to pass through a standard opening under standard head at a standard temperature (40°C or 50°C) is divided by the flow time, in seconds,

for 50 ml of water under the same standard head at 25°C. The ratio of the flow times is the Engler specific viscosity.

Typical Test Results

Specification requirements for viscosity of liquid bituminous materials consist of a maximum and minimum value at a particular temperature. Commercial materials seldom fail to meet the requirements unless they have accidentally been mixed with other materials or have lost volatiles through careless handling.

Influence of Method of Test

The viscosity tests are extremely sensitive to temperatures and require accurate temperature control for reproducible results.

Distillation Tests

ASTM Test Designation (Cut-Back Asphalts) D402-49
AASHO Test Designation (Cut-Back Asphalts) T78-49
ASTM Test Designation (Tars) D20-52
AASHO Test Designation (Tars) T52-46
ASTM Test Designation (Emulsions) D244-49
AASHO Test Designation (Emulsions) T59-49

Significance of Test

The distillation test is used to determine the quantity and characteristics of the volatile constituents and the percentage of non-volatile residue present in cut-back asphalts, tars and asphalt emulsions. In the case of the emulsified asphalts the volatile constituents are largely water.

The distillation test for cut-back asphalts and road tars is particularly valuable for determining the type of volatile in the material and hence for judging the rate of loss of volatiles under field conditions. Thus if a given cut-back cures (looses its volatiles) too slowly on a given job, then under similar conditions a cut-back with higher boiling range volatiles will cure even more slowly. The specification requirements set the maximum and/or minimum percentage of distillate which may be evaporated at the various temperatures and the minimum percentage of residue. Ranges for cut-back asphalts and tars are fairly broad so that considerable differences in curing rates may occur for a given grade of material.

The residue from the distillation test is similar to the portion of the cut-back or emulsion that remains in the pavement after the volatile portion has evaporated. The residue may be examined for its characteristics by means of the tests applied to asphalt cement and tar binders.

Synopsis of Test Method

The test methods for cut-back asphalts, tars, and asphalt emulsions differ somewhat in the details of procedure. However, the test methods all involve heating a prescribed quantity of the material in a standard flask or still at a specified rate and determining the amount of distillate removed at a series of

standard temperatures. As an example the volume of distillate for cut-back asphalts is determined at temperatures of 320°F, 347°F, 374°F, 437°F, 500°F, 600°F, and 680°F.

Typical Test Results

Distillation test results show the percent of distillate by volume, or by weight, driven off at each of the prescribed test temperatures and the percentage of residue remaining after completion of distillation.

Influence of Method of Test

Difficulties are sometimes encountered in performing the test because foaming prevents maintaining the proper distillation rate. The test results are sensitive to proper distillation rate.

Solubility Tests

ASTM Test Designation (Carbon Disulphide) D4-52
AASHO Test Designation (Carbon Disulphide) T44-42
ASTM Test Designation (Carbon Tetrachloride) D165-42
AASHO Test Designation (Carbon Tetrachloride) T45-45

Significance of Test

Bitumen is defined as that part of a bituminous material soluble in carbon disulphide. Requirements for solubility in this solvent or in carbon tetrachloride, sometimes in both, are found in specifications for most bituminous materials. Carbon tetrachloride is non-combustible and, except for its toxicity, much safer to use than highly inflammable carbon disulphide and is therefore used, whenever permissable, in place of carbon disulphide for routine solubility tests. Other solvents are also used for the same reasons. Carbon tetrachloride should not be used to determine the solubility of tars.

Insoluble material in petroleum asphalts is generally dirt picked up in storage or salt not removed in the refining process. Insolubles in tar are predominately free carbon while those in native asphalts are finely divided mineral matter. Difference in solubility in carbon disulphide and carbon tetrachloride is the quantity of carbenes. Carbenes are produced in petroleum asphalts by over heating and cracking; a content of 0.5 per cent is indicative of detrimental overheating. Because of lack of sensitivity, however, the carbene content determination is of doubtful value to detect overheating.

Solubility tests on native asphalts, tars, and rock asphalts are useful in establishing the amounts of bitumen which will be available as binder in the pavement. Some authorities believe that the ash content test is more reliable for this purpose, because of the failure of the solvents to remove dust in colloidal suspension.

One of the solubility requirements is found in nearly all American specifications for asphalt cements, tars and residues from cut-back asphalts and emulsions. A few specifications carry requirements for solubility in both carbon disulphide and carbon tetrachloride. Some agencies specify the use of other solvents and test results using these solvents are equally useful.

Synopsis of Test Method

The test procedure requires dissolving a specified quantity (about 2gm) of bituminous material in 100 ml of solvent, filtering through an asbestos mat in a small porcelain (Gooch) crucible and determining the residue retained in the crucible. The percentage of soluble material is calculated by difference.

Typical Test Results

The solubilities of native asphalts vary from a minimum of about 60 per cent for Trinidad Lake asphalt to 95 per cent for Bermudez. Road tars have solubilities of 75 per cent or more. Since petroleum asphalts are almost without exception, 99^+ per cent soluble in either carbon tetrachloride or carbon disulphide, the test generally serves no purpose for these materials other than to insure due care in refinery operations.

Influence of the Method of Test

The test requires careful laboratory work and accurate weighing. Variations in test results have been traced to differences in the minimum size of asbestos filter used in the mat.

Oliensis Spot Test

AASHO Test Designation T102-42

Significance of Test

The Oliensis spot test is valuable in indicating the degree of heterogeneity or colloidal stability of asphaltic materials. Many authorities object to the use of heterogeneity in connection with the test. Colloidal instability caused by overheating or cracking, as indicated by the occurrence of the positive spot, is of most interest in highway work. The test is quite sensitive in this respect sometimes indicating differences of as little as 40°F in the temperature to which the material was heated. This ability to detect overheating is the greatest value of the test. However, mixtures of cracked materials with normal asphalts are not always readily detected. Some asphalts will stand adulteration with considerable quantities of badly cracked materials without showing a positive spot; others will show a positive spot when small quantities of cracked materials are added.

The test procedure has been the subject of some rather heated controversies. It is rather extensively used for asphalt cements and residues of cutback asphalts intended for use in highway pavements. Specification requirements call for a negative spot in the standard solvent or for a negative spot in a specified mixture of solvent and xylene.

Synopsis of Test Methods

In the standard test 2 grams of semi-solid asphalt are dissolved in 10.2 ml of a 138 - 145 aniline point (boiling range 300 to 410°F) standard naphtha solvent. After one hour and again after 24 hours a drop of the solution is placed on filter paper. A uniform brown stain at both times is recorded as a negative test while the formation of a dark spot or ring near the center of the

stain is recorded as a positive test. The positive test is considered indicative of colloidal instability.

Several variations of the standard test procedure are in use. The test has created difficulty in some cases because many crude oils show a positive spot in the standard test and asphaltic materials prepared from these crudes also show a positive spot.

One widely used variation with positive spot materials is to repeat the test using a mixture of the standard naphtha and varying percentages of a spot retarding agent, usually xylene. The xylene is normally added in five (5) percent increments to determine the percentage required to change the spot from positive to negative. The specification in this case sets an upper limit on the amount of xylene required to suppress the positive spot.

Several Western states prefer to use normal heptane in lieu of the standard solvent naphtha. Xylene is used with the normal heptane in the same manner as described above. Specifications set an upper limit on the amount of xylene required to suppress the positive spot.

Still another variation used when the crude oil shows positive in the standard naphtha solvent is to use a naphtha solvent obtained from the particular crude oil in the same boiling range (300°F to 410°F). The test on asphaltic materials prepared from the crude oil is then run in the same manner as for the standard test; a positive spot is indicative of colloidal instability.

Typical Test Results

Results of the standard test are reported as either positive or negative. Results of the tests in which xylene is used to suppress the positive spot are reported in terms of xylene equivalent. Thus a 5 - 10 percent naphtha-xylene equivalent indicates a positive test in a mixture of 5 percent xylene and 95 percent naphtha and a negative test in a mixture of 10 percent xylene and 90% percent naphtha. A 15 - 20 percent heptane-xylene equivalent would indicate a positive spot in 85 percent heptane and 15 percent xylene and a negative spot in 80 percent heptane and 20 percent xylene.

Influence of Method of Test

The test is sensitive to solvent-asphalt ratio and to length of time in solution. The standard 5.1 to 1 solvent-asphalt ratio and the specified time periods must be closely adhered to.

Penetration Test

ASTM Test Designation D5-52
AASHO Test Designation T49-53

Significance of Test

The penetration test is used to measure the consistency of semi-solid asphaltic materials. The penetration test under a single set of conditions usually 77°F, 100 gm. load, 5 seconds time is used for classifying semi-solid asphaltic materials into standard consistency grades. Since grade does not establish quality, the single penetration test has no relation to quality. Typically specified penetration grades for asphalt cement are (77°F, 100 gm., 5 sec.):

30 - 40	85 - 100
40 - 50	100 - 120
50 - 60	120 - 150
60 - 70	150 - 200
70 - 85	200 - 300

The penetration grades are used to specify materials for use. For example materials in the 50 - 150 penetration range are commonly used for plant mix pavements. The asphalt cement furnishes the cohesion or tensile strength in the plant mix pavement with the harder materials giving higher cohesion. Generally the higher penetrations are preferred for use in colder climates, however, good pavements have been produced with relatively low penetration materials in Canada and with relatively high penetration materials in the Southern United States. Another example is the use of asphalt cements in the 120 - 300 penetration range for the inverted penetration or surface treatment type of pavement surface where a layer of asphalt is covered with a layer of stone. For such use it has been demonstrated that it is harder to get the cover stone to adhere to the lower penetration materials. When adhesion has been established, however, the bond is greater to the lower penetration material.

Penetrations made under several conditions (32°F, 200 gm. 60 sec. and 115°F, 50 gm. 5 sec. are also commonly used) will indicate the manner in which the materials change in hardness with changes in temperature. Some agencies use ratio of penetration at two temperatures to express this temperature susceptibility. Where resistance to flow at use temperatures is important, as in the use of the materials for crack filler, a relatively small change in consistency with wide change in temperature is desirable.

Asphalt cements from petroleum reduce in penetration with age and also develop cracking tendencies. Penetration values below 20 at 77°F for associated with bad cracking while cracking seldom occurs when the penetration exceeds 30. It has never been adequately demonstrated that the cracking is due to loss in penetration and probably both cracking and loss in penetration are due to a more fundamental change in the material.

Synopsis of Test Method

The test consists of determining how far a standard steel needle will penetrate into the bituminous material under standard conditions of temperature, load and time. The results are expressed in points of penetration (1 point = 0.1 mm). The material is tested in a standard container which is kept in a water bath (brine for 32°F temperature) maintained at the standard temperature during the test. Standard test conditions are 77°F, 100 gm. load, 5 sec. time and alternate test conditions commonly used are 32°F, 200 gm. load, 60 sec. time and 115°F, 50 gm. load, 5 sec. time.

Typical Test Results

Three tests are required for significant values. The individual values must not vary from the average by more than the $\frac{\text{Penetration}}{100} + 1$. Thus values of 90, 92, 93 would be acceptable while values of 89, 94, 92 would not be acceptable.

Influence of Methods of Test

Good results for the penetration test and reproducibility between laboratories are dependent upon careful attention to details of the test procedure. Temperature, time and load must be carefully controlled. Test results are affected by the time the sample stands in air before being put in the water bath, and by the time in the water bath; specified times should be strictly adhered to. The adjustment of the test needle at the surface of the sample when beginning the test and the cleanliness of the needle may also affect test results.

Water Content

ASTM Test Designation D94-46
AASHO Test Designation T55-46
ASTM Test Designation (Emulsified Asphalts) D244-49
AASHO Test Designation (Emulsified Asphalts) T59-49

Significance of Test

A requirement for maximum water content is found in nearly all specifications for slow curing cut-backs (road oils) and road tars. It is used only occasionally in specifications for emulsified asphalts, the distillation test being preferred to establish the useful asphaltic residue. The specifications for semi-solid asphaltic materials require that the material shall be free from water.

Extremely low water contents are necessary in order to avoid foaming when bituminous materials are heated to temperatures above 212°F.

Synopsis of Test Method

The water content of bituminous materials is determined by mixing a specified weight or volume of the material to be tested with a specified volume of petroleum solvent (for petroleum products) or a coal tar solvent (for tar products) and distilling in a metal still or glass flask attached to a graduated trap and water cooled reflux condenser. Distillation continues at a standard rate until no water is visible in any part of the apparatus except the bottom of the trap. The volume of water in the trap is then measured and expressed as a percentage of the original material.

Typical Test Results

The maximum percentage of water specified for slow curing cut-backs is ordinarily 0.5 per cent and for road tars 2.0 per cent by volume. The actual water contents are ordinarily well below these specified maximums.

Influence of Method of Test

Since most petroleum or tar products and water have different specific gravities and do not mix readily, careful attention must be given to obtaining representative samples of the material for testing. Some samples foam considerably during the test, particularly when the metal still is used. Careful attention to heating instructions will generally eliminate this difficulty.

Although not a part of the standard test procedure, a few drops of anti-foaming agent added prior to distillation, is sometimes used to control foaming.

Ductility Test

ASTM Test Designation D113-44
AASHO Test Designation T51-44

Significance of Test

The ductility test is one of the most controversial tests commonly found in the specifications for asphaltic materials. Some authorities are of the opinion that the test is quite valuable, others are of the opinion that it has very little value.

Most engineers agree that some property which may be variously described as plasticity, elasticity, ductility or malleability is desired in a paving asphalt. Whether or not the stretch of a thin thread of asphalt, as developed in the standard ductility test is a measure of this desirable quality is a subject on which there are many differences of opinion.

Correlation is poor between the conditions existing in the standard test, particularly with regard to film thickness and rate of strain, and the actual conditions in which the asphaltic material is used in the pavement.

The test measures the internal cohesion of the asphalt. It is rather generally considered that asphaltic materials with high ductility have been cementing properties although admittedly there are large differences in the performance of asphaltic materials of high ductility. Whether or not some ductility exists is probably more important than the exact degree of ductility. Thus a material with 100 cm. ductility is a better paving material than one with 10 cm. ductility but one with 80 cm. ductility is not necessarily better than one with 60 cm. ductility. A measure of the original ductility is not indicative of the rate of change of the ductile properties of the asphaltic material during the mixing process and pavement service life.

High ductility is characteristic of materials which show large changes in consistency with changes in temperature. Low ductility is commonly associated with pavement cracking. The air blowing process used in the manufacture of some asphaltic materials decreases ductility.

Some authorities place more faith in ductility tests conducted at low temperatures, 39.2°F or 32°F, than they do in the standard test at 77°F. It has been demonstrated that changes of 10° to 20°F in the temperature at which the test is conducted may reverse the relative order of ductility of two asphaltic materials.

Synopsis of Test Method

In the standard ductility test a briquette of semi-solid asphalt having a minimum central cross-section one (1) centimeter square is stretched to a thread at the rate of pull of five (5) centimeters per minute in a water bath at a temperature of 77°F. The maximum elongation of the thread at failure, measured in centimeters, is the ductility value. The test is used for semi-solid asphaltic materials and for residues from cut-back asphalts. The

standard procedure also provides for a low temperature ductility test to be made at 39.2°F with a rate of pull of one (1) centimeter per minute.

The test is sometimes run at 60°F with a rate of pull of five (5) centimeters per minute for materials having penetrations above 200. A temperature of 32°F and rate of pull of one (1) centimeter per minute are also used.

Typical Test Results

Most paving asphalts produced from petroleum will have ductilities in excess of 100 cm. Highly blown asphalts such as those used for crack and joint filler will have ductilities generally below 10 cm. The common specification for paving asphalts and residues of cut-back asphalts is a minimum ductility at 77°F of 100 cm. For materials harder than 85-100 penetration the requirement is sometimes modified to a minimum of the numerical value of the penetration; thus a material of 72 penetration would be required to have at least 72 cm. ductility at 77°F.

Influence of Method of Test

The test is quite sensitive to small particles of duct in the material under test, to accurate adjustment of the specific gravity of the water bath to that of the material under test, and to details of the test procedure such as temperature and rate of pull.

CONCRETE & CONCRETE AGGREGATES

The Abrasion Test

Significance of Test

The Abrasion test was first used to indicate the resistance of rock to wear by steel-tired traffic. Then followed a period in which it was used to give a comparative indication of the service life of gravel and crushed stone when used as surfacing material for all types of vehicular traffic. During the past thirty years, the abrasion test has also been used as a measure of quality of an aggregate for use in Portland Cement concrete or in bituminous surfacing construction.

Generally, the lower the percentage of wear in the abrasion test, the longer will be the service life of the aggregate on the road. Degradation of aggregate used as a cover for surface treatment is also decreased by a decrease in the percentage of wear. Results published by the Highway Research Board in 1937 indicate that, with all other factors constant, the lower the percentage of wear the higher the concrete strength. Other investigators have shown similar trends.

Synopsis of Test Methods

There are three commonly used abrasion tests of aggregate and crushed rock. These are: (1) Standard Method of Test for Abrasion of Coarse Aggregate by Use of the Los Angeles Machine, ASTM Designation: C 131-51; (2) Standard Method of Test for Abrasion of Graded Coarse Aggregate by use

of the Deval Machine, ASTM Designation: D 289-53; (3) Standard Method of Test for Abrasion of Rock by use of the Deval Machine, ASTM Designation: D 2-33. The Deval abrasion test is over 70 years old and was first standardized by the ASTM in 1908. The Deval Abrasion Test for gravel and crushed rock was first standardized by ASTM in 1928. The Los Angeles Abrasion Test was first used in 1916 by the City of Los Angeles and was adopted by the ASTM in 1937.

In all three methods a prepared sample, generally weighing between 5000 and 10,000 grams, is placed in a hollow steel cylinder of specified dimensions, and rotated for a specified number of revolutions. An abrasive charge of six to twelve steel spheres is used in the Los Angeles test and six spheres in the Deval Abrasion Test of Coarse Aggregate. An abrasive charge is not used in the Deval Abrasion Test of Rock. The percentage of wear in all three tests is the percentage loss in weight during the test, and is that weight of material which is reduced in size to the extent that it will pass a standard No. 12 sieve. The test equipment is required to meet exact specifications.

Typical Test Results

Materials tested in the Los Angeles machine have shown losses ranging from 10 per cent for extremely hard materials to as high as 90 for very soft limestones, sandstones, limerock and caliche. There is no direct relation between the loss in the Los Angeles test and the loss in the Deval test. Generally, the Los Angeles test shows higher losses than the Deval test with the same material, particularly in higher loss materials.

Specifications of the ASTM for coarse aggregates for various uses show maximum limits for percentage of wear in the abrasion test. A maximum of 40 is specified for aggregates for surface courses and surface treatments. A maximum of 50 is specified for aggregates for use in concrete, in base courses for concrete pavements and for bituminous macadam pavements. A maximum of 60 is specified for aggregates for base courses for bituminous pavements.

Specifications of the ASTM do not specify maximum abrasion loss for fine aggregates for any purpose.

For more detail on specification limits and the significance of the abrasion test the publications of the ASTM should be consulted.

The Portland Cement Association has published a list of the requirements of the various States for concrete aggregates.

Influences of the Methods of Test

The three methods of test have been standardized, and reproducible results can be obtained between different laboratories if equipment used conforms to all of the specification requirements. The Los Angeles abrasion machine has been found superior to the Deval machine in a number of respects. Tests can be made much more rapidly and accurately. The time required for making the Los Angeles test is less than twenty minutes as compared to five hours with the Deval machine. Flat and elongated particles in a sample increase the loss in the Los Angeles test much more than in the Deval test. The presence of soft or friable rock can be detected with the Los Angeles test much better than with the Deval test. There is an apparent agreement between the loss in the Los Angeles abrasion test and the service record of materials used in surface treatment construction. Dust produced in

the test does not appreciably affect the result as is found to be the case in the Deval test.

Soundness Tests of Aggregates

(ASTM C-88)
(AASHO T-104)

Significance of Test

Soundness tests are generally made to detect aggregates which may contribute to the disintegration of concrete exposed to destructive weathering, and to detect aggregates which will themselves disintegrate when exposed directly to destructive weathering.

Aggregates which break down readily in soundness tests should be regarded with suspicion for any use exposed to severe weathering. Aggregates for use in concrete which are suspect in soundness tests should be further investigated rather than rejected for use. Conversely, aggregates which survive soundness tests generally may be used with confidence.

Aggregates which contain considerable quantities of basically sound particles but have a sufficient quantity of unsound particles to cause relatively high losses in soundness tests are obviously unsuited for use in concrete. These aggregates may be suitable for use as surfacing materials provided that the unsound particles do not form objectionable material when they are altered by natural weathering.

A good evaluation of any soundness test of aggregate can be made only by correlation with the service record of the aggregate in the environment in which it is to be used. This does not detract from the value of the tests for comparing aggregates for a specific use.

Synopsis of Test Methods

Most soundness tests are performed to determine the resistance of the material to disintegration by freezing and thawing. The sodium sulphate soundness test has been the generally accepted method of test for over thirty years. Despite this acceptance, it has been widely criticized, and numerous reports have appeared which describe its unreliability with specific aggregates.

The freezing and thawing test of aggregate has not been standardized by the ASTM recently. A tentative method of test for soundness of aggregates by freezing and thawing (C 137-38T), was listed by the ASTM for a short time and then abandoned in favor of freezing and thawing tests of concrete which contained the aggregate.

In the sodium sulphate and magnesium sulphate soundness tests, an oven-dried sample of the aggregate is separated into specified sizes and immersed in a saturated solution of the salt. The solution is maintained at a constant temperature and the sample allowed to remain therein for about 18 hours. The sample is then removed from the solution and dried to constant weight. After cooling, the sample is reimmersed in the salt solution. These procedures are repeated for the specified number of cycles in the test. After the last cycle, the sample is washed to remove the salt and dried for the final

sieve analysis. The loss of material from each sieve size fraction is used in computing the soundness loss.

The freezing and thawing tests of aggregates all require a specially graded sample of the aggregate. One form of the test requires that the aggregate to tested in separate sieve sizes and that the loss be determined for each size. The other form of the test uses a graded sample of aggregate and determines the change in the gradation factor or the fineness modulus. In the more usual forms of the freezing and thawing test, the sample is alternately frozen and thawed for a specified number of cycles. A number of different freezing and thawing temperatures have been mentioned in published descriptions of the test.

Typical Test Results

When specifications for aggregates contain a requirement for soundness by the sodium or magnesium sulphate method of test, the specifications generally state both the number of cycles and the maximum allowable percentage of loss. ASTM C33-54T specifies a maximum of 12 per cent loss when sodium sulphate is used and a maximum of 18 when magnesium sulphate is used. A number of the States have requirements differing from these.

When specifications for aggregate contain requirements for soundness by alternate freezing and thawing, specific note should be made of the method, since there is little record of experience with this test.

The period of freezing in the test varies from 40 minutes to 24 hours between different test methods.

Specifications should contain a provision that aggregate which fails to meet the requirements of the soundness tests may be accepted provided it gives satisfactory results in concrete subjected to freezing and thawing tests, and produces concrete of adequate strength.

Influences of the Methods of Test

The ASTM sodium sulphate test and the magnesium sulphate test have been of great value since other methods have not been available. When the tests are performed in strict accordance with the specified methods the degree of reproducibility is fairly satisfactory. The salt tests cause the aggregate particles to disintegrate by the expansive force exerted by the formation of crystals of salt from the solution which is absorbed into the body of the particle. Some sedimentary rocks which have a high absorption disintegrate in the soundness test but have shown excellent service in concrete. Some aggregates which may cause spalling and cracking in concrete are not affected appreciably by any of the soundness tests.

The comparison of accelerated freezing and thawing tests of concrete which contains the aggregate in question to concrete that contains an aggregate of known performance, produces the most reliable information.

Resistance of Concrete to Disintegration During Repeated Cycles of Freezing and Thawing

Significance of Test

This test is performed to evaluate the resistance of concrete specimens to

disintegration in repeated cycles of alternate freezing and thawing. The change in weight, the change in length, the change in strength or the change in modulus of elasticity of the specimens are generally used as a measurement of the effect produced by the freezing and thawing. Any or all of these changes may be used in comparing the relative resistance to disintegration of different concretes or of different aggregates in concrete. The test results do not directly indicate the suitability of a concrete for a given purpose. The greatest value of the test is attained when the results are correlated to the performance of the concrete under typical conditions of exposure in structures. Without this correlation the test is limited in economic value.

The resistance of concrete to disintegration during freezing and thawing is one of the most important characteristics of concrete in locations where the concrete is subjected to this type of weathering. High strength is of little value if the concrete loses that strength in a short time. Likewise, close tolerances on dimensions of structural concrete components lose their practical value if adjacent concrete can expand permanently as much as 0.1 per cent due to lack of durability in freezing and thawing. In emphasizing this characteristic, the adverse effects which may be caused by changes in moisture content, changes in temperature and the adverse effects of aggressive waters should not be disregarded.

Synopsis of Test Methods

Freezing and thawing test methods are quite controversial, as is the interpretation of the test results. This is a natural result of attempting to simulate in the laboratory a life time of natural exposure of the concrete. Due to the practical disadvantages of attempting the duplication of the freezing and thawing cycles which occur in nature a considerable number of freezing and thawing tests have been used. The equipment required for the test is relatively expensive, consequently many expedients are used which also complicate the test and its results. Due to these reasons and others the ASTM has adopted four tentative standard methods of freezing and thawing concrete test specimens. These methods are designated as follows:

ASTM Designation C 290-52T: Resistance of Concrete Specimens to Rapid Freezing and Thawing in Water.

ASTM Designation C 291-52T: Resistance of Concrete Specimens to Rapid Freezing in Air and Thawing in Water.

ASTM Designation C 292-52T: Resistance of Concrete Specimens to Slow Freezing and Thawing in Water or Brine.

ASTM Designation C 310-53T: Resistance of Concrete Specimens to Slow Freezing in Air and Thawing in Water.

The test specimens used in these tests are prisms which are made and cured in accordance with the applicable requirements of the "Tentative Method of Making and Curing Compression and Flexure Specimens in the Laboratory" (ASTM Designation: C 192). The test is generally started on the specimens when they are 14 days old. They are placed in the apparatus at the beginning of the thawing phase, subjected to a number of cycles of exposure to the freezing and thawing cycle and removed from the apparatus in a thawed condition. In this condition, they are weighed, measured or tested for fundamental transverse frequency, and then returned to the freezing and thawing apparatus.

Typical Test Results

Effects of the test are expressed in various ways at a specified number of cycles of freezing and thawing. The per cent loss in weight, the per cent change in length, the per cent loss in strength and the durability factor all have been used in some methods. The loss in weight was used to some extent in early freezing tests. It may be indicative of quality of some concretes but it does not show the structural damage to the concrete which in many cases cannot be seen in its early stages. Strength tests or nondestructive sonic modulus of elasticity tests will indicate unseen damage to the concrete. Loss in flexural strength and loss in sonic modulus show fairly good correlation. The change in length also is directly related to the loss in strength and shows good correlation for many concrete mixes.

There is no specific change in strength or change in length which can be used as a direct controlling limit for all concretes. These values must be correlated with the field performance of the concrete before specific values have definite meaning. There are numerous cases on record where a loss in sonic modulus of 30 per cent or an increase in length of over 0.06 per cent in 200 cycles of freezing and thawing is associated with severe deterioration of the concrete in field structures. The conditions of exposure are so different that these values have no meaning except to the areas of similar exposure. It is extremely dangerous, at this time, to establish limits in freezing and thawing tests of concrete except for local areas or conditions.

Influences of the Methods of Test

Freezing and thawing tests have been performed which will disintegrate the best concrete in a relatively short time. The type of test desired is one which will distinguish between the good and bad concrete in as short a period of time as possible. Both the good and the bad concrete can have widely different physical characteristics and can contain many different cements and mineral aggregates. Therefore, it is not unusual to expect that many factors would affect the results obtained in one particular method of test. The effect of different methods of test on the concrete may be considerable.

Factors affecting the results of the freezing and thawing test are characteristics of the materials used in the test specimen, the preparation of the test specimen, the moisture condition of the aggregate and of the cement paste in the specimen during freezing and thawing, the size and spacing of the air voids in the cement paste in the specimen and the relative size of the largest piece of aggregate and the size of the specimen.

Other factors affecting the results of the tests are the temperatures at the beginning and at the end of the freezing cycle and of the thawing cycle, the rate of freezing and the rate of thawing and how the freezing proceeds through the specimen. Different results are obtained when the freezing proceeds uniformly from one face of the specimen to the opposite face than when the freezing proceeds from all faces of the specimen toward the longitudinal axis and toward the center of the specimen.

The Slump Test

(ASTM C-143)
(AASHO T-119)

Significance of Test

The slump test is intended to give a relative measure of the consistency or degree of wetness of fresh portland cement concrete. When mixtures vary only in water content, the value of slump is a good measure of workability. When mixtures vary in characteristics of cement and aggregates or in proportions, the numerical value of slump does not in itself adequately express relationships such as cohesiveness, ease of placement and finishing, resistance to segregation and other properties that may be grouped under the general heading of workability. By observation of the mixture during and after the performance of this test, it is possible to obtain indications of the cohesiveness and placeability of the mix.

Test Methods

The standard test method, ASTM Designation: C 143 is used both in the laboratory and in the field. The test is not applicable when there is an appreciable amount of coarse aggregate over 2 inches in size. The test specimen is formed in a mold which is in the form of the lateral surface of the frustum of a cone with the base 8 inches in diameter, the top 4 inches in diameter, and the altitude 12 inches. The concrete is placed in the moistened mold in three layers, each approximately one-third the volume of the mold. Each layer is rodded 25 strokes with a steel rod 5/8 inch in diameter, 24 inches in length, having one end rounded to a hemispherical tip. After the mold is filled and struck off, it is immediately lifted carefully and vertically from the concrete. The slump is the difference in height in inches of the concrete before and after the removal of the mold.

Typical Test Results

Normal concreting materials in usual proportions produce concrete mixtures which have slumps generally from one-half to five inches. Differences in workability at a given slump may occur in mixes differing considerably in the amount or nature of the fine aggregate or in the amount or kind of cement. This also may occur between mixes containing rough and angular coarse aggregate in comparison to those containing smooth, well-rounded coarse aggregate.

If the slump is not extreme, some comparative information may be obtained by observation of the type of slump and by manipulation of the concrete mass after measurement of the slump.

Influences of Methods of Test

The test can be reproduced quite closely if proper attention is given to the sampling and details of performance of the test. However, erratic results may result if the cement has a tendency toward false set or premature stiffening. It is fairly sensitive to differences in materials, quantity of cement and water. The elapsed period of time after mixing and also after deposition may affect the value of the slump, so time should be taken into consideration when

good reproducibility is desired. Slight differences in other external factors have little effect on the test.

Sieve Analysis of Fine and Coarse Aggregates

(ASTM C-136)
(AASHO T-27)

Significance of Test

Sieve analysis is the procedure used to determine the particle size distribution of fine and coarse aggregates. Sieves with square openings are generally used, although the method may also be used with screens having round openings. Sieve analyses are generally made to determine if aggregates comply with specified gradings. In portland cement concrete, variations in the grading of the aggregate result in variations in the amount of cement required to produce concrete of a given strength and quality. Proper aggregate grading contributes to the uniformity, workability, and plasticity of the concrete. Improved workability generally permits a decrease in the amount of mixing water which in turn gives an increase in strength or allows the cement factor to be reduced.

Synopsis of Test Methods

Samples used for sieving are prepared by quartering or by the use of a sample splitter. The sample is then separated into various sizes, using sieves complying with the material specification. The sieving operation may be either a mechanical operation or may be done by hand, moving the sieve laterally and vertically with a jarring action to keep the sample continuously in motion until separation of sizes is complete. The size of the sample varies with the maximum particle size of the aggregate. For example, a minimum of 500 grams should be used for concrete sand and a minimum of 10 Kg. for 1" top size coarse aggregate.

Typical Test Results

The results of a sieve analysis are reported either as: (a) Total percentages passing each sieve, (b) Total percentages retained on each sieve, or (c) percentages retained between consecutive sieves. A typical concrete sand then may be reported as follows:

(a)		(b)		(c)	
Sieve Sizes	Percent Passing	Sieve Sizes	Percent Retained	Sieve Sizes	Percent Retained*
3/8 in.	100	3/8 in.	0	3/8 in. to No. 4	2
No. 4	98	No. 4	2	No. 4 to No. 8	11
No. 8	87	No. 8	13	No. 8 to No. 16	19
No. 16	68	No. 16	32	No. 16 to No. 30	22
No. 30	46	No. 30	54	No. 30 to No. 50	28
No. 50	18	No. 50	82	No. 50 to No. 100	15
No. 100	3	No. 100	97	Pan	3

* Between consecutive sieves.

Influences of the Methods of Test

This test is easily reproduced providing the sample to be screened is carefully split or quartered, thoroughly dried and the sieving operation carried out as specified.

Flexure Test of Concrete

(ASTM C-78)
(AASHO T-97)

Significance of Test

The flexural strength of concrete is of importance in concrete structures whenever beam action is present or where there is stress because of contraction due to temperature change or shrinkage. Flexure tests of concrete beams are particularly useful in determining the time when concrete pavements may be safely opened to traffic or curing terminated and are widely used, therefore, in highway construction. The flexural strength of concrete may be determined in several ways. Specimens are tested sometimes as cantilever beams, sometimes as simple beams with a centrally applied load, and also as simple beams with the load applied at the third points. The latter method is generally considered to be the most accurate and the first two types, that is, the cantilever and the simple beam tests, are often referred to the third point loading test which is the present standard.

The value obtained for the modulus of rupture of concrete is not an absolute quantity, but depends a great deal on the method used to perform the test. Different forms of specimens are used, together with different types of loading, different sizes of machines and other variables, therefore the results are not comparable with one another. However, these results do serve a useful purpose since with any given set of conditions they provide a means of comparing the flexural strength of any concrete to another. To provide a better means of comparison, it is highly desirable to express the results of various beam tests in terms of the standard test method (third point loading) by means of a factor which can be determined experimentally for each machine and method.

Synopsis of Test Methods

Flexural strength is generally expressed in terms of "modulus of rupture," which is the calculated fiber stress at rupture using the flexure formula $S = \frac{Mc}{I}$ where: S = the stress in the fiber most remote from the neutral plane, M = the resisting moment or bending moment at the section being considered, I = the moment of inertia of the cross section of the specimen, and c = the distance from the neutral plane to the outermost fiber of the beam.

Test specimens are cast with the long axis horizontal in rigid, non-absorptive watertight molds. A specimen should be at least 2" longer than three times the depth as tested and have a ratio of width to depth of not more than 1.5. Concrete is placed in the mold in approximately 3-inch deep layers, each layer being thoroughly rodded and then spaded along the sides and ends.

Following the rodding and spading of the top layer the surface of the beam is struck off with a straight edge and finished with a float. Following the moist curing, the specimen is then tested as follows (Third point loading, ASTM C 78):

1. Bearing blocks set to the desired span are placed in the testing machine.
2. The test specimen turned on its side with respect to the position when molded is then centered on the bearing blocks.
3. Load applying blocks are then brought in contact with the upper surface of the beam at the third points between the supports. Note: If full contact is not obtained between the specimen and the blocks and supports due to surfaces being out of plane the specimen must be capped.
4. The load is then applied by the testing machine rapidly up to approximately 50% of the breaking point, after which the loading rate is reduced and applied at such a rate that the increase in extreme fiber stress does not exceed 150 psi, per minute.
5. The load at breaking point is recorded and the modulus of rupture computed.
6. Since the moment of inertia of the cross-section bears directly on the test result, it is necessary that the specimen be measured to the nearest 1/10 inch to determine both the average depth of the specimen at the section of the plane of failure, and the average width.

Typical Test Results

The results of the flexure test are reported as modulus of rupture in pounds per square inch together with the method of test used. For example, the modulus of rupture of six-bag concrete used for highway pavement might have a modulus of rupture of 550 pounds per square inch at 7 days. The same concrete tested either as a cantilever beam or as a simple beam with a load at the center would probably have a higher reading since available data indicates that the results by either of these two methods is generally higher than that obtained by the third point loading method.

Influences of the Methods of Tests

Reproduction of test results is generally good providing the specimens are tested strictly in accordance with specifications. It is essential that the specimens be properly made, cured, centered in the testing equipment and the load applied at the proper rate. The temperature and moisture condition of the specimen apparently affect greatly the resulting modulus of rupture. It is suggested that the temperature of the specimen at time of test be closely controlled and that the concrete in the specimen be of uniform moisture content, not having a partially dried exterior with a moist center.

The Amount of Material Finer than No. 200 Sieve in Aggregate

(ASTM C-117)
(AASHO T-11)

Significance of Test

Large amounts of clay and silt in aggregate are objectionable since they are often present in the form of adherent coatings of such character than the coating adheres to the aggregate up to the time that it is finally in place in the concrete and may therefore interfere with the resulting bond. Of the two, clay adheres the more tenaciously as a coating. In addition to the fine coating resulting from silt and clay, there are those which result from dust accumulation. These are generally stone dust developed during the crushing of stone or similar materials and ordinarily do not adhere firmly to the stone, and therefore can be easily removed by washing. The ordinary concrete mixer will probably dislodge fine materials of this type and they will be harmful only to the degree to which they increase the percentage of fines present in the mix. A high percentage of this type of fine material might require more water for workability of the concrete, thus increasing the water-cement ratio. This test does not distinguish between clay, silt and stonedust.

Synopsis of Test Methods

The minimum sample required ranges from approximately 500 grams for sand, that is material passing the No. 4 sieve, up to about 5 kg. for aggregate of 1 1/2" top size or over. The test sample is first dried, then weighed and placed in a pan or vessel of sufficient size so that it may be agitated vigorously in water without loss of any of the sample or water. The water is then poured immediately over two nested sieves, the lower being a No. 200 sieve, the upper approximately a No. 16 sieve. The agitation must be sufficiently vigorous to completely separate the coarse particles from the finer particles, that is, finer than the No. 200 sieve, and to bring the fine material into suspension, so that it may be removed by decantation of the wash water. The addition of water to the sample, the agitation of water and sample and the pouring off of the wash water is continued until all the fine material is washed from the sample and the wash water is clear. All material retained on the nested sieves is then returned to the washed sample and the sample dried to constant weight. The weight lost by washing is then divided by the original dry weight and multiplied by 100 to give the percentage of material finer than No. 200 sieve.

Typical Test Results

Specifications usually limit the amount of material finer than No. 200 sieve to not over (1) 1% for coarse aggregate; (2) 3% for fine aggregate used in concrete subject to abrasion and (3) 5% for fine aggregate used in concrete not subject to abrasion. Higher limits are often permitted for manufactured sand where the fines are essentially dust and not clay or shale.

Influences of the Methods of Test

The results of this test are usually easily reproduced if the test is conducted as specified. However, the test is difficult to reproduce with some

materials, since there is no distinct end point at which the water becomes "clear." Whenever the fine material adheres tightly to the larger pebbles, washing must be continued until all of the fines are loosened and brought into suspension so they can be decanted with the wash water.

Compression Testing of Concrete

(ASTM C-39)
(AASHO T-22)

Significance of Test

The compressive strength of concrete is one of the most important qualities in structures inasmuch as most plain and reinforced concrete structures are designed on the principle that the effective concrete area will be stressed only in compression. The compression test does not only measure the quality of the concrete as to strength, but also serves as an indication of other properties of concrete including the concrete-making properties of the materials used in the mix. Several types of specimens may be used for determination of compressive strength including cast concrete cylinders, cores drilled from concrete in place, sections of beams which have been previously tested in flexure, and cubes, which are extensively used in Europe. In this country the cylinder is generally considered to be standard. Normally a 6" x 12" cylinder is specified where the coarse aggregate does not exceed 2". Larger specimens are used for larger size coarse aggregate maintaining the relationship of the height being twice the diameter of the specimen.

Synopsis of Test Methods

Standard (6" x 12") concrete cylinders are made by placing concrete in a standard mold in 3 layers of approximately equal volume. Each layer is rodded with 25 strokes of a 5/8" rod the end of which is rounded to a hemispherical tip, 5/8" in diameter. The rodding is distributed uniformly over the cross-section and penetrates into the underlying layer. After the top layer has been rodded and the sides of the mold tapped to close voids left by the tamping rod, the surface is struck off and covered to prevent evaporation.

The ends of all specimens that are not plane within 0.002 inches are capped. The caps must be within 0.002" of a plane and approximately at right angles to the axis of the specimen. After the caps have hardened sufficiently, the cylinders are tested for strength in a testing machine equipped with two steel bearing blocks with hardened surfaces, one of which is spherically seated. The load must be applied continuously and without shock to the specimen. In hydraulically operated machines, the load is applied at a constant rate within a range of 20 to 50 psi per second. For screw-type machines the head travels 0.05 inches per minute when the machine is running idle. The compressive strength of the specimen is then calculated by dividing the maximum load carried by the specimen during the test by the average cross-sectional area of the specimen.

Typical Test Results

The compressive strength of the concrete varies with several factors

including the type of cement, the amount of cement used per cubic yard, the water-cement ratio, the air content, and to a lesser degree the gradation and the other characteristics of the aggregates. Strength is also affected greatly by curing conditions and by testing procedure. Compressive strengths based on tests of 6" x 12" moist cured cylinders of properly designed concrete tested at 28 days will generally approximate those given in the following table:

Water-cement ratio, gal. per bag of Cement	Probable compressive strength at 28 days, psi.	
	Non-airentrained Concrete	Air-entrained Concrete
4	6000	4800
5	5000	4000
6	4000	3200
7	3200	2600
8	2500	2000
9	2000	1600

Influence of the Methods of Test

Reliable reproducible strengths within acceptable coefficients of variation are obtained when they are determined under standardized conditions. To provide good reproducibility the sampling, handling, making, curing, and testing of the specimens must be uniform. In testing a concrete specimen in compression, it is essential that the bearing areas of the specimen are properly prepared to assure uniform districation of the load over the entire area, that the specimen is centered in the machine and that the load is correctly applied.

ACKNOWLEDGMENTS

The Committee is deeply appreciative of the help we have been given. Each discussion has been submitted to the critical review of a great many practicing Highway Engineers. The Highway Division ASCE set-up several years ago a list of State Highway Department contact men. These men themselves either reviewed our work or found the proper person within their Highway Department. All the suggestions, comments and criticisms were gathered together and the final drafts of the various discussions reflect this help. The Committee feels that almost all of the objections are satisfied and that the result is vastly improved.

Respectfully submitted,

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Paper 1386 September, 1957 HW 4

Journal of the
HIGHWAY DIVISION
Proceedings of the American Society of Civil Engineers

METROPOLITAN TRAFFIC AND HIGHWAY PROBLEMS

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(Proc. Paper 1386)

Metropolitan Growth

Toronto is situated on the north shore of Lake Ontario and like many an early settlement it was created as a trading post at a point of access to water transportation. The growth of the city was due mostly to its geographical location which made it the hub of a system of communications for the development of trade with other parts of the country. During the succeeding years, industry, commerce and housing concentrated close to the lake shore and to the main east and west road and railway facilities and to the harbour area.

Over the years other communities formed in the vicinity under individual political control and grew to the point where only the political boundaries separated each of these municipalities. By 1930 there was a clearly defined Metropolitan area of 240 square miles which included the city of Toronto, three villages, four towns and five urban townships. The whole area constituted one economic and social unit but was governed by 13 administrative councils.

Many of the major problems which confront the area at this time are the direct result of the form of growth and the rate at which it has taken place. With heavy financial obligations to provide municipal services it is not surprising that the development of transportation facilities did not keep pace with this growth.

The increase of hundreds of thousands of people in the suburbs of our large cities is one of the many phenomena which have occurred during our generation. It is one of the major changes of our times producing many urban problems and destined to affect the way of life of a large segment of our population.

The expansion of all large cities on the North American continent has been the result of similar circumstances and conditions. One is that during two world wars a tremendous influx of people moved into the cities to swell the production lines. Having tasted the benefits of urban living the majority of these people stayed within its orbit and assisted its further growth. In

Note: Discussion open until February 1, 1958. Paper 1386 is part of the copyrighted Journal of the Highway Division of the American Society of Civil Engineers, Vol. 83, No. HW 4, September, 1957.

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Toronto and other Canadian cities the end of the war was followed by a tremendous influx of people from other countries anxious to start a new life in a new land.

Another important, if not the most important contributing factor to urban expansion, was the automobile. It put people on wheels and gave them a mobility they had never experienced before.

At the beginning of this century Toronto was a city with a population of 200,000. Today, and almost 60 years later, the city and the 12 municipalities have a population of 1.3 million with a spiralling rate of growth which has reached an average increase of 45,000 per year. While the city of Toronto and its surrounding areas had grown steadily for many years the remarkable expansion which now characterizes the area really became evident in 1948/9.

From 1941 to 1948 the total population of the area increased at a rate of slightly more than 1% per year. Since 1948 the annual population increase has averaged about 4%. Today the population of Metropolitan Toronto comprises over 25% of the population of Ontario and over 9% of the national population.

These recent developments have substantially altered the balance of population between the city and the suburbs. Before 1939 the city contained nearly three quarters of the total population of the Metropolitan area. By 1947 its share of the total was still about 70% but was down to 49% by 1956. Between 1947 and 1956 the three outer suburbs comprising 76% of the Metropolitan area, accounted for nearly 85% of the total population increase in Metropolitan Toronto. The total increase during this 8 year period was almost 353,000 persons or 30% of the 1948 population.

Even more striking than the population increase has been the rate at which land areas have developed. In 1947 the total developed area was 64 square miles. Since 1947 an equal area of land has been absorbed and the remaining land is being developed at the current rate of 7 square miles each year. Compared to the population increase of 32% during the past 8 years the development of land has increased by 100%.

It is anticipated that the present population of Metropolitan Toronto will increase within 20 years from 1.3 million to 2.3 million, with practically the entire growth of one million people occurring in the three outer suburbs. In addition it is expected that the population of the surrounding fringe area municipalities within the Planning area will increase during the same period from about 100,000 to half a million. The population of the Planning area is expected to double, increasing from 1.5 million at 1956 to 2.8 million at about 1980. At 1956 there were over 400,000 vehicles registered in Metropolitan Toronto and it can be confidently anticipated that vehicle registrations will at least double by 1980.

Metropolitan Administration

The extension of the area and the development of large tracts of land within a short period of time created a demand for municipal services for which the resources of the suburban municipalities were totally inadequate.

Until 1953 the form of municipal government would not permit the area to capitalize upon its great opportunities. For 40 years development was impeded by the fact that there were 13 individual autonomous municipalities, each standing in its own way and standing in the way of its neighbours and

standing in the way of the development of the whole area. There was no way whereby the Metropolitan services required by the area could be provided. Some municipalities were rich, others were nearing bankruptcy. Our major streets were plugged with a never ending caravan of motor vehicles and there was no way to cure this state of affairs.

With the occurrence of such dynamic and accelerating growth and the accumulation of area-wide problems that threatened to strangle that growth it became apparent that certain problems of an area-wide nature could not be solved within individual political boundaries of such a tightly knit and integrated geographical entity.

To help solve these problems the municipality of Metropolitan Toronto was incorporated on April 2, 1953, to come into active existence in January, 1954. Under the Metropolitan Toronto Act the 13 municipalities are combined together into a Metropolitan Corporation whose duty it is to provide those services of a Metropolitan nature while the local municipalities still administer those services which are local in nature.

Co-ordinated Transportation Administration

The Corporation has now been in active existence for 3-1/2 years and one of its functions has been the creation of various agencies to study, plan and implement the transportation needs of the area. To discharge this task three departments have been created, each of which serves a separate function but co-ordinated by the Metropolitan Technical Committee comprising the heads of these departments.

The Metropolitan Planning Board was established on September 1, 1953. In addition to the 240 square miles of Metropolitan Toronto the Planning area includes fringe municipalities with an area of 510 square miles. This creates a planning area of 750 square miles within which traffic and highway planning can be undertaken. The Transportation Division of the Board is responsible for the preparation of a master transportation plan which will form part of the Official Plan. The Board also prepares preliminary functional designs of new highways and improvements to all major roads which were assumed as Metropolitan roads.

The Metropolitan Roads department is concerned with the engineering and maintenance work of all Metropolitan roads as well as the preparation of all construction drawings and the supervision of construction work.

Finally, the Traffic Engineer is concerned with traffic operation and the constant problem of moving a huge number of vehicles on roads designed to only perform a limited function.

Although not recognized as a department of the Metropolitan Corporation the Toronto Transit Commission is a public body charged with the provision and operation of public transportation services throughout the Metropolitan area. The Commission was established in 1921 as the Toronto Transportation Commission of the city of Toronto and assumed control of all transportation companies operating at that time. The Commission can request money from the Metropolitan Corporation and the latter may issue debentures for the Commission.

At the beginning of this year a Metropolitan Police Force was inaugurated by combining the separate forces of the 13 municipalities. At the present time Metropolitan Toronto has an almost unified administration to handle its

traffic and highway problems. The exception is a Parking Authority which although operating very effectively in the City has not yet achieved Metropolitan status.

Having briefly outlined the growth of the Metropolitan area, the establishment of the Metropolitan administration and the various divisions charged with the task of solving our traffic and highway problems it remains for me to give you some idea of the problems that have been tackled, the remedial measures which have or are being adopted and finally what has been accomplished within 3-1/2 years.

Metropolitan Transportation System

The 66-foot township road allowance, erratically surveyed into existence in the late 19th century, provides the basic road system of the area. I used the word "erratically" because for some unaccountable reason a tremendous number of "jogs" or "T" junctions occur at what should have been simple crossroad intersections. These roads are spaced 1-1/4 miles apart and are orientated north-south and east-west to provide a checkboard pattern of 1000 acre squares. Most of these roads in the three outer suburbs are rural in character having 24' or 28' pavements with gravelled shoulders draining into open ditches. In the city and inner suburbs a high proportion of the major roads have street car services operating down the centre of the road.

Depending on their traffic significance 280 miles of these roads were adopted as Metropolitan roads in January 1954. Several miles of Provincial Highways were included in this total. Most of the streets are still owned and operated by the local municipalities. Between 1950 and 1956 the Province of Ontario constructed a limited access expressway north of the city and extending between the eastern and western boundaries of Metropolitan Toronto. At its east and west extremities it joins the Lakeshore Road which runs east-west along the lakefront. At the present time these are the two most heavily travelled roads within the area accommodating both local and through traffic.

The deep ravines of the Don and Humber River systems divide the Metropolitan area into three large segments. The direction of the major roads in relation to these natural barriers creates a series of major traffic problems. In many cases the continuity of the major roads are broken at these barriers thereby influencing the distribution of traffic and overloading the available roads crossing these travel barriers. A series of barriers has also been created by railways resulting in over 200 level crossings and a constant crop of fatal accidents.

Although planning schemes had from time to time been produced showing a network of expressways and rapid transit lines the individual municipalities could never agree on planning, alignment and financing. In any case, such schemes lacked comprehensive traffic analysis and the estimates of future growth on which the plans were based were quickly overtaken as population and vehicle registrations climbed rapidly.

A Short and Long Term Transportation Plan

With a booming urban area, traffic congestion, inadequate roads and financial obligations to provide other much needed services what could be done to solve the traffic and highway problems of the area?

Two things are being done:

1) A short term plan designed to safeguard future foreseeable road widening requirements, the improvement of traffic conditions, the reconstruction or repair of the worst sections of road and the construction of some new roads.

2) A long term plan to study and analyse travel characteristics, estimate future growth and the distribution of development and, finally, to prepare a transportation plan as part of the Official Plan of the area.

Short Term Plan

To safeguard the future right-of-way of all major roads of the area, particularly those subject to development, a preliminary right-of-way plan was prepared and approved by Council. The plan was developed in conjunction with a study of existing and anticipated land use, building lines, desirable highway standards and estimated traffic generation. A minimum width of 86' was adopted and then increasing to 100, 120, 150, 200 and over for expressways. The plan is subject to constant amendment as the planning schemes of the municipalities are consolidated in conjunction with Metropolitan requirements.

The most urgent task of improving traffic flow on existing roads was for the most part the problem of the Traffic Engineer. A staff was established to take traffic counts at all intersections and congestion points so that studies could be made to improve traffic signal timing and turning traffic. On the basis of these studies traffic timing was improved and certain turns at problem intersections were prohibited at various times of the day.

A constant source of friction on major roads was the curb parking of vehicles. On many roads double parking was a common occurrance as trucks were unable to park to service business premises. Now the situation has changed. During the past two years curb parking has been prohibited at peak traffic periods on all but 3 miles of Metropolitan roads. Similar by-laws have also been passed by local municipalities to cover their own major roads. Although an outcry was registered by business organizations against such action it is now a recognized necessity and off-street parking lots are slowly, although reluctantly, being established by group business interests. A "No Stopping" ban is also rigidly enforced on a large number of heavily travelled roads at certain times of the day.

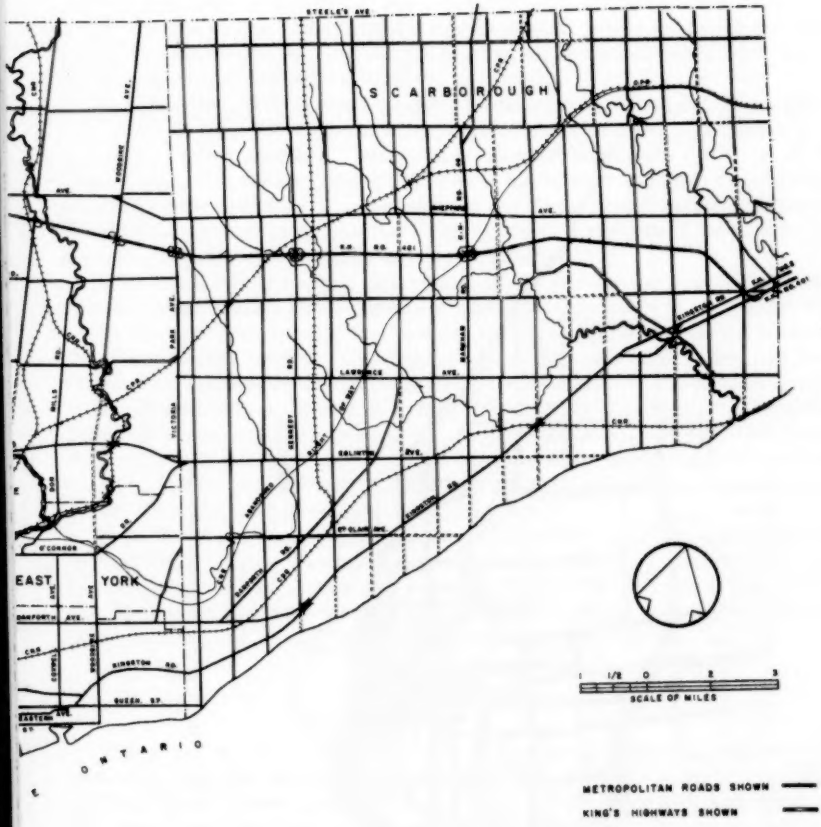
A small but effective improvement to assist traffic flow has been the construction of bus-bays particularly at road intersections. This has been accomplished with the cooperation of the Toronto Transit Commission.

The most important assistance to traffic flow on existing roads has been the redesign of intersections to facilitate turning traffic. Based on a study of the intersection, turning lanes are being introduced with short medians to channel traffic and to serve as pedestrian refuges. Of the 300 or more intersections to be redesigned about 1/3 of these have been completed in the Planning office and a large number constructed. In conjunction with this program of improvement the "jogs" I mentioned previously, and which are the source of considerable traffic congestion, are being corrected, in many cases involving the redevelopment of corner properties.

With these improvements being made it was also appreciated that certain

METROPOLITAN TORONTO PLANNING BOARD 1956.

Fig. 1. Metropolitan Roa


STEELES AVE
SCARBOROUGH
EAST YORK
ONTARIO
SCALE OF MILES
METROPOLITAN ROADS SHOWN
KING'S HIGHWAYS SHOWN

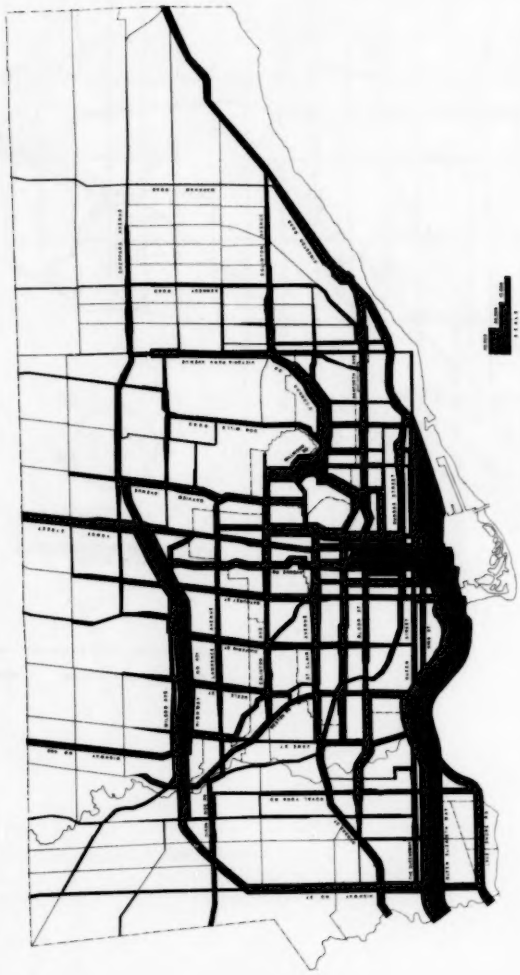


Fig. 2. Daily Vehicular Volumes.

controls should be placed on land use development with undesirable traffic generation. In this way roads of a limited capacity would not become subjected to excessive traffic or local frictions that would seriously disrupt their use as a major traffic road. The design of points-of-access to such developments as Service Stations, Shopping Centres and subdivisions are also controlled as a condition of approval to develop.

To bring the existing Metropolitan roads up to arterial road specifications and at the same time to construct a system of expressways, considerable expenditures are necessary. Many miles of suburban roads are to be completely reconstructed to provide 4 traffic lanes with adequate foundations and drainage, new bridges are necessary to replace one and two lane structures, thirty level crossings on Metropolitan roads are to be over or under-passed and channelized intersections are to be constructed.

This work, together with new roads, is very necessary to the area but is seriously handicapped by financial considerations. Only a comparatively small amount of this work can be done within the financial straight jacket of the Metropolitan budget. The small portion that is available for use is also affected by increasing construction costs which, according to data compiled by the United States Bureau of Public Roads, have increased by 230% since 1940. A choice also has to be made as to what proportion shall be spent on existing roads and how much on new expressways which would considerably improve traffic circulation of the area, relieve the existing road system and assist the continued development of the area.

In 1956 the capital expenditure on Metropolitan projects was $38 million, of which $14 million was spent on roads. The current estimates for Metropolitan projects have increased to $43 million, of which about $20 million are to be used for road works. Since 1954 the annual road expenditures have increased from $4.1 million to the current estimate of $20 million.

Long Term Plan

The study of travel characteristics of the area, the future distribution and nature of land use development and its traffic generation ability is being studied by the Metropolitan Planning Board. In conjunction with these studies the Board has also been given the responsibility of producing functional plans of transportation facilities and the presentation of a 20 year transportation plan.

I mentioned that many of the major problems which confront the area are the direct result of the form and rate of Metropolitan growth which has been both numerical and physical. Suburban development created two big problems. The provision of adequate services such as sewers, watermains, schools, welfare, roads etc. and the influence of intra-urban traffic. City traffic also increased at the same time but the automobile is not such a necessity as in the suburbs since 75% of all jobs exist in the city and since a considerable proportion of their social, recreational and shopping activities are found in the city. Because of the low density of suburban development - 5 houses to the acre and less - public transportation is restricted - with 38 bus lines operating at a loss. The automobile is consequently the beast of burden and an indispensible part of suburban living.

As in most cities the peak traffic creates the major problems. In Toronto this is particularly serious as traffic converges on the downtown area from

Fig. 3. Major Employment Areas.

its limited approaches to the west, north and east. A worker O-D survey completed in 1954 and a study of employment distribution shows that at the present time the city has 75% of the employment of the entire Metropolitan area. Of this, 68% (representing 374,500 workers) are concentrated in and around the downtown area with one in four workers travelling by automobile. From the 3 outer suburbs 60% of the workers travel by automobile compared to 24% by city workers and 40% by workers of the middle or inner suburbs.

One of the most far reaching considerations that have to be made concerns the use and location of expressways and rapid transit. As population increase in arithmetic ratio, transportation needs grow in geometric ratio. Twice as many people and goods have to be moved and they have to be moved roughly twice the distance. This is particularly so because current and future development occurs and will occur at considerably lower densities than prevail presently on the average. The trend toward lower densities is noticeable in industrial and commercial as well as in residential developments. This trend, in part a result of automobilization, increases the demand for vehicular movement, both of passengers and goods, and for a road system to serve this movement. It has, therefore, sometimes been assumed that the automobile will supercede all other forms of public transportation within Metropolitan Areas and that all efforts should be concentrated on developing the road system.

The road system has a well defined function.

1. Movement of goods can only be handled by trucks in most cases, therefore roads for truck movement must be provided.

2. Roads must be provided for access to all properties.

3. Persons' Movements which are dispersed in space and/or time, can be handled only by the private automobile, except for very short distances which may be handled by pedestrian movement.

4. Persons' Movements between dispersed points and points of concentration cannot be handled for their entire length by any means of public transportation. In these cases the private automobile must act as a feeder to points of transfer to public transportation, at which points parking facilities must be provided.

These four needs must be provided by a road system. It must handle truck movements, access to property and all passenger movements except those concentrated in space and time which may be handled by public transportation.

It is obviously economical to provide to the maximum possible extent for concentrated passenger movement by rapid transit and for diffused passenger movement and truck traffic by a system of express highways. There are, however, definite limits to the possibility of concentrating movements on expressways and rapid transit lines. It is frequently overlooked that the overwhelming majority of all movements of persons and goods within a Metropolitan area are short movements.

The origin and destination surveys in the U.S.A. show that trucks make considerably more short trips than passenger automobiles. The Metropolitan Toronto trucking survey paid special attention to this question. From an analysis of a truck O-D survey it was determined that 23% of all truck trips were less than 1 mile in length and 53% less than 3 miles. Similar data are

also observed from studies of person trips.

It follows that expressways cannot substitute for the street system even if it were possible to build them to the capacity required for such a purpose. They can only concentrate the longer movements and distribute into the street system at as many points as can be suitably located. The expressways under construction or planned in the Toronto Metropolitan Area all converge on the downtown and waterfront districts. Determination of the required capacity and best location of the routes and their interchanges must be based on the results of a number of studies of survey now in process of tabulation and analysis.

Similarly, rapid transit is not a substitute for, but a supplement to public surface transportation. It can function only, if, where and when loads are sufficiently concentrated. In general, such concentration can be brought to the stations by pedestrian movement only in the central business district. The success of the Yonge Street subway line is mostly due to its excellent integration with the surface transit system which is unrivalled in any other city. Maintenance and improvement of the surface transit system has been proved to be indispensable for the proper functioning of rapid transit.

Where densities are still lower, passengers will have to reach the rapid transit stations by private car. However, it is doubtful whether any transit line can operate exclusively on feeding by private car. For one thing, if all passengers for a 40,000 one-way transit load were to drive to the stations, they would require a total of 200 acres of parking area. On the other hand, if these 40,000 passengers cannot be captured by public transit and insist on driving downtown, the same parking area will be required there, in addition to five 6-lane expressways to bring them to this destination.

It is now accepted as axiomatic that the transportation problem which must be solved is how to provide facilities for the movement of an ever-increasing number of people and motor vehicles. It is obvious that the prevailing condition will grow steadily worse as our population increases and that it cannot be solved by constructing a succession of arterial highways, which will be filled the day they are opened and constitute an irresistible invitation for a continuously increasing number of motor vehicles to pour into the central city and thereby require the expenditure of further millions of dollars to accommodate them with parking space. By the same token the absolute necessity of a fundamental system of arterial highways cannot be denied nor can they be indefinitely or any longer postponed. There are strong and vocal proponents of subways at the expense of a fundamental system of highways and there are an equal number of vocal proponents of arterial highways and expressways at the expense of rapid transit.

Rapid transit and arterial highways are only two metropolitan services which the Metropolitan Corporation must provide. In the discussions which take place as to the priority which should be given to rapid transit and arterial highways, such essential services as water supply, sewage disposal facilities, schools, aged persons' homes, moderate and elderly persons' housing and a large number of collateral projects must also be considered. It is the responsibility of the Metropolitan Council to make its decisions and to adopt a plan within its financial ability which will permit it to provide all the metropolitan services which are its responsibility.

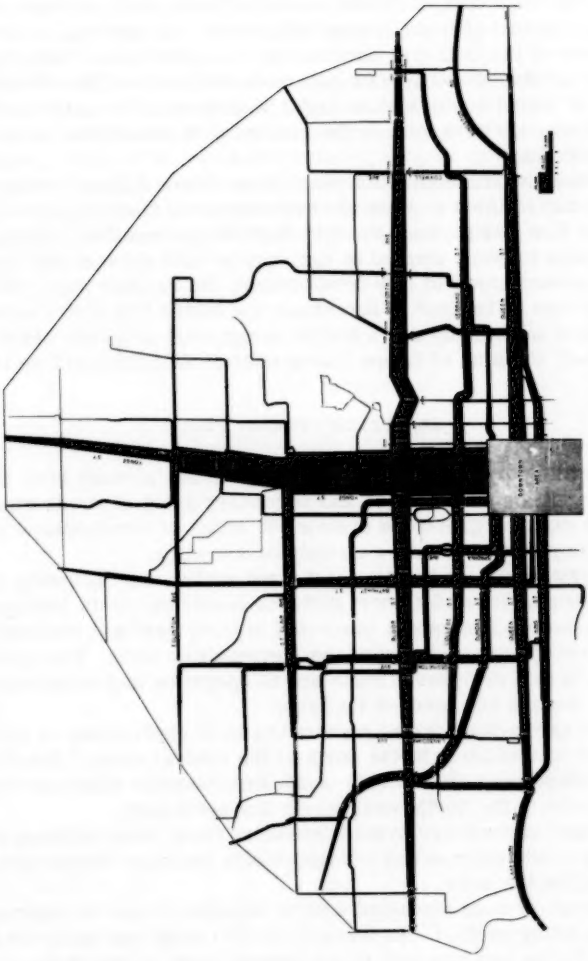


Fig. 4. Daily Public Transit Passenger Volumes.

Transportation Studies

A transportation plan is built upon a comprehensive study of the physical, social and economic characteristics of the Planning Area. This involves the study of existing and future population and land use and trends in travel habits.

To obtain information on travel habits of all persons making trips in the study area a number of origin and destination studies have been carried out. Such surveys provide data on travel characteristics such as times of travel, the beginning and end of trips, the mode of travel and the trip purpose.

On the basis of the O-D trip information it is possible to show the demand for travel by all directions by time and mode of travel. Theoretically these desire lines of travel - which show high travel demand to and from the city centre - indicate in a general way the approximate location of major transportation facilities.

To determine the transportation plan of the future it is necessary to estimate the trip distribution and travel characteristics between future land use development. For this purpose the trip distribution resulting from present-day O-D surveys is being studied in conjunction with present-day land use. Taking into account areas of new development, the relationships which are found to occur are to be used to determine the future trip distribution. Based on the results of such study and a traffic assignment program which is now being developed, the plan of future transportation facilities will be completed.

The Transportation Plan

A considerable part of the transportation plan has already been tentatively designed. In addition to the major and secondary arterial roads which are defined by the existing grid-road system, 80 miles of expressways are proposed to supplement the 40 miles already in operation.

The expressway system has two east-west routes, one following the lakefront and the second located a short distance inside the north Metropolitan boundary. These two routes are connected at their east and west extremities and thus enclose the greater part of the Metropolitan area. The north and west sections of this peripheral route are in operation and construction of the lakeshore section commenced last year.

To improve cross-town travel a short length of expressway is being studied to pass immediately to the north of the central area of the city. This route would connect with three north-south expressways which are needed to serve the suburbs to the north-west, north and north-east.

The integrated expressway system resulting from these existing and proposed routes provide expressway transportation facilities within three miles of any point within the area.

A rapid transit system combined with or separate from the expressway system is also being studied. As a result of O-D study and analysis a rapid transit right-of-way was included in the central route of one of the three north-south expressways. The cross-town intermediate expressway route now being studied includes an appraisal of both combined and separate facilities.

At the present time it is estimated that the total cost of the proposed portion of the expressway system will be about $250 million, exclusive of rapid

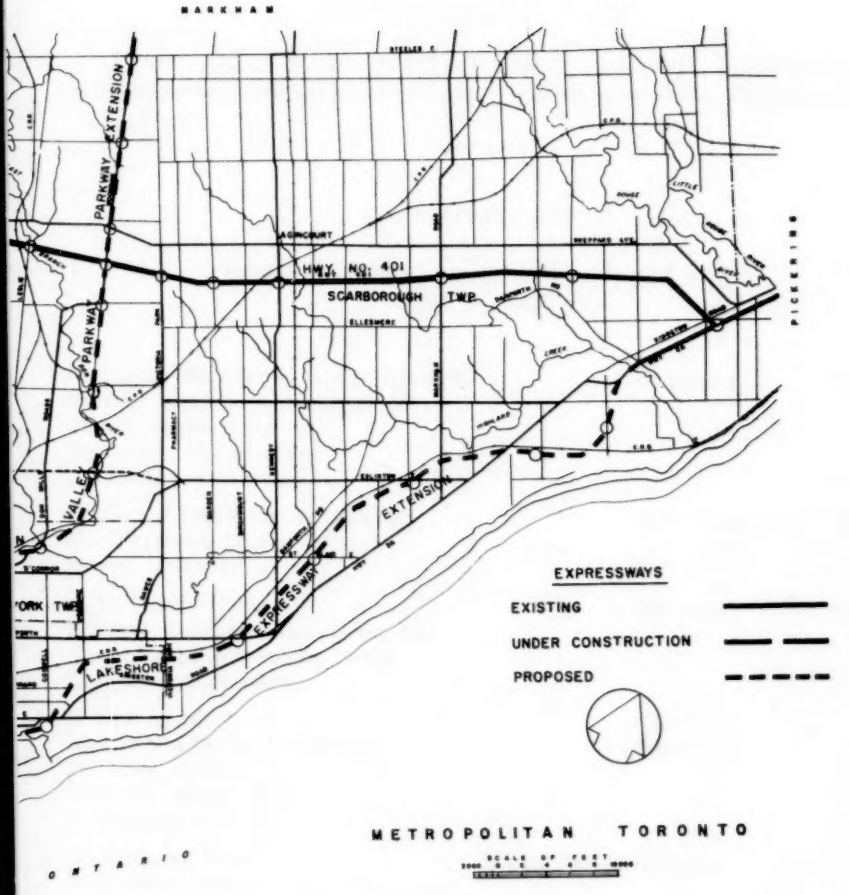
transit track and operational equipment.

CONCLUSION

I am sure that the traffic and highway problems of Metropolitan Toronto and the corrective measures that are being undertaken are basically no different from those of the majority of expanding urban centres on the North American continent. However, the form of administration of Metropolitan Toronto which permits a coordinated attack on these problems is new to this continent.

The past 3-1/2 years have shown very emphatically that to solve the problems of interrelated communities in an efficient manner it is of the utmost importance to have coordinated transportation administration which permits a joint appreciation of the overall problem. Only in this way has it been possible for Metropolitan Toronto to take an objective and unbiased view of its transportation needs and make headway toward the provision of an efficient transportation system that for 40 years before 1953 was only talked about.

Fig. 5. Expressway Key M



EXPRESSWAY KEY MAP

DIVISION ACTIVITIES
HIGHWAY DIVISION
Proceedings of the American Society of Civil Engineers

NEWS

September, 1957

HIGHWAY DIVISION EXECUTIVE COMMITTEE
1956 — 1957

Professor Harmer E. Davis (Zone IV) Institute of Transportation & Traffic Engineering University of California Berkeley 4, California	Chairman	1958
William A. McWilliams (Zone II) 43 E. Division Street Dover, Delaware	Vice Chairman	1959
A. N. Carter (Zone III) Lindsey, Carter & Associates, Inc. Tonka Terrace Shopping Center Excelsior, Minnesota	Member	1960
J. Paul Buckley Automotive Safety Foundation 200 Ring Building 1200 18th Street, N.W. Washington 6, D. C.	Member Secretary	—
R. Robinson Rowe 2701 Third Avenue Sacramento 18, California	Board Contact Member	1956-1957

Service on Executive Committee will expire in October of year listed opposite name.

Lowell E. Gregg Assistant Director of Research State Department of Highways 132 Graham Avenue Lexington, Kentucky	Board Contact Member	ASCE Research Committee

Note: No. 1957-18 is part of the copyrighted Journal of the Highway Division of the American Society of Civil Engineers, Vol. 83, HW 4, September, 1957.

HIGHWAY DIVISION
September 15, 1957

Principal items of news to be passed along to the members of the Highway Division are 1) an appeal by the Executive Committee for more and better papers for publication, and 2) announcement of the Highway Division sessions planned for the October meeting of the Society in New York City.

REQUEST FOR PAPERS FOR PUBLICATION

The Executive Committee of the Highway Division asks your help in obtaining more papers of better quality on highway engineering subjects for publication by the Society. Well prepared papers on the many subjects of current interest are of help to all highway engineers.

Membership in the Highway Division nears the 5,000 mark, placing it among the largest of the Technical Divisions, yet the ratio of published papers to division membership is one of the smallest. Both quality and quantity of papers are contributing factors.

It is the earnest hope of the Executive Committee that you will promote the publication of good papers, both by preparing material yourself and encouraging others to do so. As you know, oral presentation at a meeting is not necessary. A paper may be prepared with publication only in mind.

The Highway Division's Committee on Cooperation with Local Sections is also working on this project so you may be able to help your Local Section.

There follows a description of some of the requirements of the Society for processing papers. The Technical Publications Handbook has the complete story.

Your help will be greatly appreciated.

J. P. Buckley, Secretary,
Executive Committee
Highway Division

NOTES ON PREPARATION OF PAPERS PROPOSED FOR ASCE PUBLICATIONS

The paper proposed for publication should be sent by the author to the Manager of Technical Publications, American Society of Civil Engineers, 33 West 39th Street, New York 18.

If accepted, the paper may be used for Civil Engineering, Journals of Technical Divisions (containing material of technical reference value), or Transactions (containing papers meriting preservation in permanent form). Some restrictions of style, form and content (listed below) applying to Proceedings do not necessarily apply to papers published in Civil Engineering.

Papers (consisting of one ribbon copy and two duplicate copies) must be submitted to the Manager of Technical Publications, on double-spaced letter-sized sheets, written on one side only. They should be written in the third person with all personal references avoided. Mathematics, line drawings,

photographs, and tables are reproduced directly from author's copy. Illustrations and tables should be placed within an invisible 6-1/2 x 10-1/2 inch frame which will be reduced in the ratio of 100 to 69. Papers should average about 12,000 words and be no longer than 18,000 words.

The paper must not have been printed by anyone else and becomes the exclusive property of the Society. The Society's policy of release is liberal, when application is made.

The Society's Technical Publications Handbook gives complete details for submission of papers and the inside front cover page of the Journal of the Highway Division lists the minimum requirements.

Your help will be sincerely appreciated.

Executive Committee
Highway Division, ASCE

August, 1957

NEW YORK CITY MEETING
October 15-17, 1957

Edward S. Olcott, Executive Assistant to the Director of Port Development, The Port of New York Authority, is making arrangements for the Highway Division sessions at this meeting. An excellent program has been prepared and it should be of great interest to all members of the Highway Division. Full details will be published in Civil Engineering.

The theme selected for the four speaking sessions are:

1) "THE INTERSTATE SYSTEM IN URBANIZED AREAS - AN ADMINISTRATIVE PROBLEM FOR ALL LEVELS OF GOVERNMENT"

2) "LOCATION AND DESIGN PROBLEMS IN URBAN AND RURAL AREAS"

3) "NEW DEVELOPMENTS IN TRAFFIC ENGINEERING"

4) "CURRENT DEVELOPMENTS IN METROPOLITAN NEW YORK'S ARTERIAL HIGHWAY SYSTEM"

In addition, one of the sessions will end with the showing of a film prepared by the U. S. Steel Corporation, dealing primarily with the highway engineer and his job. There also will be a bus tour which will cover many of the modern express highways in the New York area, both completed and under construction.

PROCEEDINGS PAPERS

The technical papers published in the past year are identified by number below. Technical-division sponsorship is indicated by an abbreviation at the end of each Paper Number, the symbols referring to: Air Transport (AT), City Planning (CP), Construction (CO), Engineering Mechanics (EM), Highway (HW), Hydraulics (HY), Irrigation and Drainage (IR), Pipeline (PL), Power (PO), Sanitary Engineering (SA), Soil Mechanics and Foundations (SM), Structural (ST), Surveying and Mapping (SU), and Waterways and Harbors (WW), divisions. Papers sponsored by the Board of Direction are identified by the symbols (BD). For titles and order coupons, refer to the appropriate issue of "Civil Engineering." Beginning with Volume 82 (January 1956) papers were published in Journals of the various Technical Divisions. To locate papers in the Journals, the symbols after the paper numbers are followed by a numeral designating the issue of a particular Journal in which the paper appeared. For example, Paper 1113 is identified as 1113 (HY6) which indicates that the paper is contained in the sixth issue of the Journal of the Hydraulics Division during 1956.

VOLUME 82 (1956)

SEPTEMBER: 1054(ST5), 1055(ST5), 1056(ST5), 1057(ST5), 1058(ST5), 1059(WW4), 1060(WW4), 1061(WW4), 1062(WW4), 1063(WW4), 1064(SU2), 1065(SU2), 1066(SU2)[c], 1067(ST5)[c], 1068 (WW4)[c], 1069(WW4).

OCTOBER: 1070(EM4), 1071(EM4), 1072(EM4), 1073(EM4), 1074(HW3), 1075(HW3), 1076(HW3), 1077(HY5), 1078(SA5), 1079(SM4), 1080(SM4), 1081(SM4), 1082(HY5), 1083(SA5), 1084(SA5), 1085(SA5), 1086(PO5), 1087(SA5), 1088(SA5), 1089(SA5), 1090(HW3), 1091(EM4)[c], 1092 (HY5)[c], 1093(HW3)[c], 1094(PO5)[c], 1095(SM4)[c].

NOVEMBER: 1096(ST6), 1097(ST6), 1098(ST6), 1099(ST6), 1100(ST6), 1101(ST6), 1102(IR3), 1103 (IR3), 1104(IR3), 1105(IR3), 1106(ST6), 1107(ST6), 1108(ST6), 1109(AT3), 1110(AT3)[c], 1111(IR3)[c]; 1112(ST6)[c].

DECEMBER: 1113(HY6), 1114(HY6), 1115(SA6), 1116(SA6), 1117(SU3), 1118(SU3), 1119(WW5), 1120(WW5), 1121(WW5), 1122(WW5), 1123(WW5), 1124(WW5)[c], 1125(BD1)[c], 1126(SA6), 1127 (SA6), 1128(WW5), 1129(SA6)[c], 1130(PO6)[c], 1131(HY6)[c], 1132(PO6), 1133(PO6), 1134(PO6), 1135(BD1).

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JANUARY: 1136(CP1), 1137(CP1), 1138(EM1), 1139(EM1), 1140(EM1), 1141(EM1), 1142(SM1), 1143(SM1), 1144(SM1), 1145(SM1), 1146(ST1), 1147(ST1), 1148(ST1), 1149(ST1), 1150(ST1), 1151(ST1), 1152(CP1)[c], 1153(HW1), 1154(EM1)[c], 1155(SM1)[c], 1156(ST1)[c], 1157(EM1), 1158 (EM1), 1159(SM1), 1160(SM1), 1161(SM1).

FEBRUARY: 1162(HY1), 1163(HY1), 1164(HY1), 1165(HY1), 1166(HY1), 1167(HY1), 1168(SA1), 1169(SA1), 1170(SA1), 1171(SA1), 1172(SA1), 1173(SA1), 1174(SA1), 1175(SA1), 1176(SA1), 1177(HY1)[c], 1178(SA1), 1179(SA1), 1180(SA1), 1181(SA1), 1182(PO1), 1183(PO1), 1184(PO1), 1185(PO1)[c].

MARCH: 1186(ST2), 1187(ST2), 1188(ST2), 1189(ST2), 1190(ST2), 1191(ST2), 1192(ST2)[c], 1193 (PL1), 1194(PL1), 1195(PL1).

APRIL: 1196(EM2), 1197(HY2), 1198(HY2), 1199(HY2), 1200(HY2), 1201(HY2), 1202(HY2), 1203 (SA2), 1204(SM2), 1205(SM2), 1206(SM2), 1207(SM2), 1208(WW1), 1209(WW1), 1210(WW1), 1211(WW1), 1212(EM2), 1213(EM2), 1214(EM2), 1215(PO2), 1216(PO2), 1217(PO2), 1218 (SA2), 1219(SA2), 1220(SA2), 1221(SA2), 1222(SA2), 1223(SA2), 1224(SA2), 1225(PO)[c], 1226 (WW1)[c], 1227(SA2)[c], 1228(SM2)[c], 1229(EM2)[c], 1230(HY2)[c].

MAY: 1231(ST3), 1232(ST3), 1233(ST3), 1234(ST3), 1235(IR1), 1236(IR1), 1237(WW2), 1238(WW2), 1239(WW2), 1240(WW2), 1241(WW2), 1242(WW2), 1243(WW2), 1244(HW2), 1245(HW2), 1246 (HW2), 1247(HW2), 1248(WW2), 1249(HW2), 1250(HW2), 1251(WW2), 1252(WW2), 1253(IR1), 1254(ST3), 1255(ST3), 1256(HW2), 1257(IR1)[c], 1258(HW2)[c], 1259(ST3)[c].

JUNE: 1260(HY3), 1261(HY3), 1262(HY3), 1263(HY3), 1264(HY3), 1265(HY3), 1266(HY3), 1267 (PO3), 1268(PO3), 1269(SA3), 1270(SA3), 1271(SA3), 1272(SA3), 1273(SA3), 1274(SA3), 1275 (SA3), 1276(SA3), 1277(HY3), 1278(HY3), 1279(PL2), 1280(PL2), 1281(PL2), 1282(SA3), 1283 (HY3)[c],1284(PO3), 1285(PO3), 1286(PO3), 1287(PO3)[c], 1288(SA3)[c].

JULY: 1289(SM3), 1290(EM3), 1291(EM3), 1292(EM3), 1293(EM3), 1294(HW3), 1295(HW3), 1296(HW3), 1297(HW3), 1298(HW3), 1299(SM3), 1300(SM3), 1301(SM3), 1302(ST4), 1303 (ST4), 1304(ST4), 1305(SU1), 1306(SU1), 1307(SU1), 1308(ST4), 1309(SM3), 1310(SU1)[c], 1311(EM3)[c], 1312(ST4), 1313(ST4), 1314(ST4), 1315(ST4), 1316(ST4), 1317(ST4), 1318 (ST4), 1319(SM3)[c], 1320(ST4), 1321(ST4), 1322(EM3), 1323(AT1), 1324(AT1), 1325(AT1), 1326(AT1), 1327(AT1), 1328(AT1)[c], 1329(ST4)[c].

AUGUST: 1330(HY4), 1331(HY4), 1332(HY4), 1333(SA4), 1334(SA4), 1335(SA4), 1336(SA4), 1337(SA4), 1338(SA4), 1339(CO1) 1340(CO1), 1341(CO1), 1342(CO1), 1343(CO1), 1344(PO4), 1345(HY4), 1346(PO4)[c], 1347(BD1), 1348(HY4)[c], 1349(SA4)[c], 1350(PO4), 1351(PO4).

SEPTEMBER: 1352(IR2), 1353(ST5), 1354(ST5), 1355(ST5), 1356(ST5), 1357(ST5), 1358(ST5), 1359(IR2), 1360(IR2), 1361(ST5), 1362(IR2), 1363(IR2), 1364(IR2), 1365(WW3), 1366(WW3), 1367(WW3), 1368(WW3), 1369(WW3), 1370(WW3), 1371(HW4), 1372(HW4), 1373(HW4), 1374(HW4), 1375(PL3), 1376(PL3), 1377(IR2)[c], 1378(HW4)[c], 1379(IR2), 1380(HW4), 1381(WW3)[c], 1382(ST5)[c], 1383(PL3)[c], 1384(IR2), 1385(HW4), 1386(HW4).

c. Discussion of several papers, grouped by Divisions.

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